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A Review on Big Data Analytics for Energy Efficiency, Conservation and Management in Energy Intensive Manufacturing Industries

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Abstract: Due to the increasing demand and energy cost have made many Energy Intensive Manufacturing Industries to find out the smart ways to monitor, control and save energy. So, the Smart Manufacturing is made an important tool for Education, Research and Energy Intensive Manufacturing Industries. The paper reviews on understanding of Energy Big Data; "5V" Characteristics of Energy Big Data Analytics such as volume, velocity, variety and value; Energy Big Data Analytics; Effective Utilization of Energy Big Data concepts like Data Core, Data Collection, Data Pre – Processing, Data Mining and Presentation of Energy Data; Role of Smart Manufacturing in Energy Intensive Manufacturing Industries; Energy Efficiency, Conservation and Management using Big Data Analytics Approach; that are used to manage the energy consumption in residential, commercial and industrial sectors.

Keywords: Big Data Analytics, "5V" CharactePristics, Smart Manufacturing, Efficiency, Conservation and Management.

I. INTRODUCTION

In the present world, Big Data is used as a large amount of energy consumption data and the advanced concepts of Big Data have made the new research known as Energy Big Data. The extensive researches in Energy Big Data Analytics have made new ways to understand consumption of Energy in Energy Intensive Manufacturing Industries [1, 4]. To reduce the Co_2 Emissions, save money and develop the sustainable technology, the smart manufacturing is taken into consideration which may lead to implementation of new energy management systems. Due to the increasing demands and energy cost have made many Energy Intensive Manufacturing Industries to find out the smart ways to monitor, control and save energy by the use of the "5V" Characteristics of Energy Big Data Analytics like Volume, Velocity, Variety, Value and Verification that have made the consumers the to retrieve the energy data at lower cost, developed system and higher Energy Efficiency [2-3]. Hence, this review paper gives the complete information of how the Big Data Analytics can be used in day- to- day life of Energy Intensive Manufacturing Industries and therefore two case studies are explained based on increasing energy efficiency, proper conservation of energy and energy management.

II. LITERATURE REVIEW

A. Energy Big Data

Energy Big Data is a term used for collection of large and complex data i.e collection of energy data which are huge in size by using traditional data managing tools for storing or processing the data efficiently [4-5, 7].

B. "5V" Characteristics of Energy Big Data

1) *Volume:* Big data means lots and lots of data. In energy sector, the wide deployment of smart metering devices (e.g., smart meters) created massive amounts of data. For instance, for a distribution network with 1 million smart meters deployed, the amount of electricity consumption data collected in one year is very large. It is the amount of electricity consumption data collected by 1 million smart meters in a distribution network within one year i.e the amount of electricity consumption data collected once every 15 mins by 1 million smart meters within one year will be up to 2920 TB. This presents not only a storage problem, but an analytic problem of making sense of all that data [1-5, 7-8].
2) *Velocity:* Velocity is the speed of energy big data collection, processing and analysis. Comparing the traditional post-processing type business intelligence and data mining, the collection and processing of energy big data need surprising speed. To support the near real-time decision-makings in energy system, the speed of data collection and processing ranges from sub-second to 5- or 15-mins intervals [1-5, 7-8].
3) *Variety:* Energy big data has a high amount of variety. Generally, it is a mix of structured (e.g., the energy consumption data), semi structured (e.g., data exchanged between smart energy management platform and third-party data aggregators using XML, Web services), and unstructured data (e.g., email or SMS notification about energy use, interactions of consumers on social media about their energy use). There are also some energy data within the industry i.e inside-industry data (e.g., electric vehicle-related data) and outside-industry data (e.g., weather data) in the energy big data. These different types of data all combined will result in a significant increase in the complexity of energy big data applications [1-5, 7-8].

4) *Value:* The value of Big Data is difficult to evaluate in. Firstly, extracting value from Big Data is tough because of the hurdles caused by the previous four factors. Secondly, it is challengeable to examine the impacts on the insights, benefits and business processes within both sectors. Thirdly, the value of reports, statistics, and decisions obtained from Big Data is hard to measure due to the large influences on micro and macro perspectives [1-5, 7-8].
5) *Verification:* There is a great number of bad data (e.g. noises, inaccurate attributes, etc.) from data which should be verified so that good data could be picked out. The verification usually has to be carried out under certain authorities and security levels. Thus, the verification process designed and developed as tools to automatically verify the quality and compliance issues may consider different situations, some of which may be so complex that it is challengeable to address [8].

C. Energy Big Data Analytics

Energy Big Data Analytics is an advanced tool for analyzing the concepts and techniques for handling the huge data; it is used to retrieve the information i.e information about the hidden patterns, unknown correlations, market trends, customer preferences for the industries. It is a technology used to monitor, collect and large the large amount of energy related information through electronic sensors, smart grid technologies, electricity supply, grid operations and customer demands [2-3, 4, 6].

D. Concept of Energy Big Data Analytics Platform

The Energy Big Data Analytics Platform is shown below in Fig. 1.

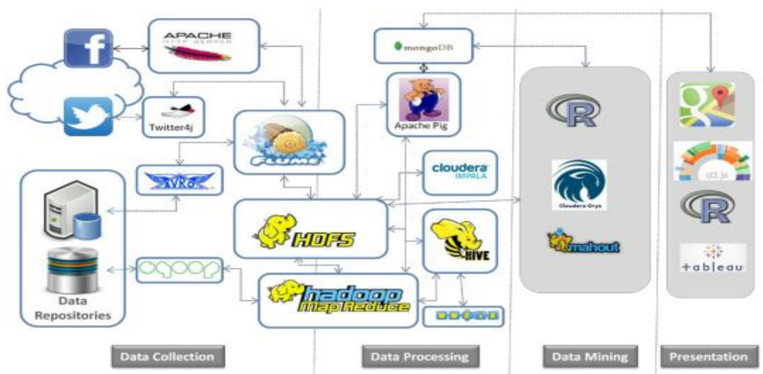

Fig. 1 Concept of Energy Big Data Analytics platform [3]

1) *Data Core*: The two components are shared between data collection and data processing steps as:
a) *Apache Hadoop:* Apache Hadoop is a framework that allows the distributed processing of the large energy data sets across clusters of computers.
b) *HDFS:* HDFS is a distributed file system that provides high throughput access to application data thus providing a highly efficient and scalable solution for handling Energy Big Data [3, 17].
2) *Data Collection:* The Big Data platform is capable of collection and aggregation of data from the multiple data streams i.e. social media data, consumer data, or server log files etc. The Energy data can be live streaming data or data residing in server file systems or databases. Energy data can be collected as it is so there are no dependencies on format or structure of the data. Some filtering can also be applied while collecting the data.

Following two components are recommended for data collection:
a) Apache Flume: Apache Flume is used for efficiently collecting, compiling and moving large amounts of data. Flume can then ingest data directly into the HDFS. Flume can also read from databases and it is particularly useful while reading from document stores.
b) Apache Sqoop: Apache Sqoop is designed for efficiently transferring bulk data between relational databases and Hadoop. In most of the energy consumer data cases Sqoop can be used to collect data and feed it into the HDFS through running multiple parallel Hadoop MapReduce jobs [3, 17].
3) *Data Pre–Processing*: The data available in HDFS can be normalized to structured formats. Then the processing techniques can be applied to get it ready for further text mining. Pre-processing of the energy data also helps in filtering out the unwanted information to make the data lighter for the mining process. In the proposed model, Apache Pig and Hive are used to pre-process the data. Apache Pig and Hive both use Hadoop MapReduce as parallel batch processing [3, 17].

4) *Data Mining*: The real value of any analytics platform lies in its ability to make sense of the data. Energy data collection and data pre-processing modules of the platform can bring and normalize data from multiple streams to be further analyzed by the data mining modules in the platform. There are various open source data mining and statistical analysis tools available on-line with the power of most advanced machine learning, text mining and statistical modelling algorithms built in them. The proposed platform can provide a 'plug n play' environment for most of these tools to be applied on use case requirements [3, 17].
5) *Presentation*: The tools are used to build interactive dashboards which can be able to zoom in and out of energy data. They should provide a flexible way to manage visualizations based on use cases and can be integrated into web based applications or mobile applications [3, 17].

E. Role of Smart Manufacturing in Energy Intensive Manufacturing Industries

The manufacturing industry consists of 27% of global final energy consumption in 2014, and the demand for energy resources in the manufacturing industry is expected to keep rising as the development of world economies. Sustainable energy is one of the means to reducing the CO_2 impact on the environment and improves energy sustainability. Hence, sustainable energy is the most important tool to reduce pollution and greenhouse gas emissions from the source, and lead to improved energy sustainability during the whole product cycle. The Smart Manufacturing technologies have a great influence in the energy industry and help to facilitate the deployment of sustainable energy. The cost of electricity from solar photovoltaic and wind falls rapidly. From 2010, the prices for new solar photovoltaic have come down by 70%, wind by 25% and battery costs by 40%, and the sustainable energy is affordable to not only developed countries but also developing countries. The impacts of smart manufacturing technologies in the energy industry are reflected in two major aspects [9, 13]. Smart manufacturing technology can improve the performances or reduce the cost of production in energy devices, such as energy collect devices and energy storage devices. The Energy factories can be turned into "smart energy factories" with the help of smart manufacturing technology. The performance improved in energy manufacturing devices and energy manufacturing processes can help the energy industry to meet the increasing demands of energy resources, and can also enhance the energy sustainability from the source. In order to analyze the energy efficiency of different technologies in the smart factories, the three-level hierarchies are as follows: process level, machine/station level, and factory level [9].

1) *Process Level:* In this level, Practice includes the research and innovation regarding fundamental physical phenomena, the emerging methods or technologies that are different with the legacy techniques, as well as the applications of new energy. Here, the facts refer to losses of energy brought by physical mechanisms, such as material reflectivity, heat transfer, and heat waste. Some researchers argue that the energy waste at this level is not important for comparison with the total energy usage. The improvement can be seen in the 4th industrial revolution, considering that IoT becomes a critical in the smart factories. For example, the electronic devices or machines performance is greatly dependent on the performance of the cooling system. The basic of the process of cooling and heat transfer can increase the efficiency of the cooling unit, thus enhancing the machine's energy efficiency and reducing energy waste. Another example involves tool degradation. The process of degrading the tool almost exists in any manufacturing process and is the source of many undesirable outcomes, e.g., deteriorated product quality, increased production costs due to change and redevelop, and reduced energy efficiency of machines. The Study tells that tool degradation greatly develops the machine behaviour and defines a limit to the device. The Study of recycling heat waste in a certain process contributes to the conservation of energy and reduces energy waste. Innovative manufacturing is a process which consumes less energy and also important for sustainability. For Example, ultrasonic metal welding has been popularly adopted in various industrial applications, such as lithium-ion battery assembly, automotive body construction, and power device packaging, due to this greater advantage over traditional fusion welding techniques. Two important advantages of this process are its short cycle time and low energy consumption [9].
2) *Machine/Station Level*: Machine/station level tells about the integration of different processes. The energy use in this level is the sum of all the processes. The energy efficiency (Eff_m) at this level is given as:

$$Eff_m = E_{process} / E_{consumed} \quad \text{…. (1)}$$

The Equation 1 shows the energy efficiency of the machine level is proportional to the energy usage of the processes. The wastage of energy in the single process may not be a large percentage of the overall energy waste. Hence, the energy efficiency of the process level has a crucial impact on the energy efficiency of the machine level. In fact, doubling energy efficiency at process level will lead to doubling efficiency at the machine level [9].

3) *Factory Level:* In this level efficiency is not only a sum of all the lower levels, but a result of interaction among all subsystems. At this level, the facilities and machines are interconnected. Improving only the single component may have a significant impact on the others since the whole system is working as an entity. The technologies applied at this level change the energy efficiency by vertical and horizontal integration, which is one of the essential features that distinguish smart manufacturing and traditional manufacturing. The common researches on smart manufacturing are big data analytics and machine learning, which mainly optimizes the performance at this level. By adaptively allocating resources, optimally scheduling operations, and improving decision-making, the energy and materials waste is reduced, and sustainability is thus enhanced [9].

F. Energy Efficiency, Conservation and Management using Big Data Analytics Approach

In Industry 4.0, global interest has accelerated digital transformation in the process manufacturing industry, including the oil and gas sector. Most of the companies have engaged in technology pilots to explore options for reducing costs and increasing overall equipment effectiveness and regulatory compliance. The excellent ways to hold these new innovations is to apply advanced industrial analytics to production data generated by sensors. All the energy data provide unique opportunities for improving energy efficiency. Energy can be saved by achieving the various ways that are; through change in daily behaviour (switching off the light), through installations of more energy-efficient equipment, through equipment maintenance or through optimization of process and ensuring the use within the best operating zones. Optimization of process and asset performance is probably the biggest area for energy savings, but it requires a deeper understanding of the operational process and asset data [10-11]. The dynamic energy management is enabled by Big Data & Analytics in Smart grids. Smart grids enable a two-way flow of data and power between consumers as well as suppliers. This helps in the optimization of power in terms of reliability, energy efficiency, and power sustainability [16]. This way energy consumers and energy producers take a more active role in the electricity market and thus, management of dynamic energy. The Effective dynamic power management very much dependent on load forecasting and production of renewables. This is an alarming situation for intelligent methods and solutions, including machine algorithms for analysis of large data volumes generated by the enormous number of smart meters. Therefore, for optimized smart grid operation efficient data network management, robust data analytics, high-performance computing, and cloud computing technology are critical. As Big Data Analytics is successfully used to analyze, monitor and predict the process and asset performance of energy management. This example is related to energy consumption within the cooling water network. For cooling the water, Reactors consume cooling capacity from the utility network to cool water. For these reactors, sufficient cooling capacity is critical as thermal runaway could occur when the available capacity is insufficient. To avoid this undesirable situation, a monitoring system using advanced analytics was set up. Early warnings were created and only triggered on actual problematic situations, avoiding false positive alarms that could be triggered by measurement noise or spikes in the data. Rebalancing of the reactors and deprioritize other equipment, so that critical systems can consume the maximal cooling capacity and the total energy consumption is within target boundaries, this can be done when the process engineer and operators receives the warning have ample time. Another example is a predictive maintenance case for fouling of heat exchangers. The controlled cooling phase is the most time-consuming in a reactor with subsequent heating and cooling phases. Fouling of the heat exchangers increases the cooling time, but scheduling maintenance too early leads to unwarranted downtime, and scheduling too late leads to degraded performance, increased energy consumption and potential risks. A cooling time monitor was set up for enabling timely maintenance, which extended the asset availability and reduced the maintenance cost and safety risks. All these benefits, including controlled energy consumption, ultimately led to a 1%-plus overall revenue increase of the production line [9-10].

III.BENIFITS, LIMITATIONS AND APPLICATIONS OF BIG DATA ANALYTICS IN ENERGY INTENSIVE MANUFACTURING INDUSTRIES

A. Benefits of Big data in Energy Intensive Manufacturing Industries

1) *Power generation planning:* Optimization can be done by utility companies for their power planning and generation using analytics. There are two key decision-making processes in power generation -power planning and dispatching of the economic load. Once we gather all the data from multiple sources, there are multiple models run on top of that data to arrive at power planning. Economic load dispatch means matching energy demand with the optimal power supply from the grid over a specific time frame.
2) *Efficient and accurate forecasting:* Data analytics helps in accurately forecasting the energy consumption which plays a pivotal role in the generation and thus, dynamic pricing. Similarly, it plays an important role in forecasting the power generation, especially for renewable energy sources which include solar as well as wind, which gets impacted due to changing weather conditions. This all gets taken care by doing predictive analysis on all the data taken from weather systems.

3) *Site selection:* All the data is integrated be it energy production, energy consumption, GIS, and weather data like wind direction, temperature, humidity, atmospheric pressure, cloud, and wind speed can support the selection of sites where renewable power generation devices have to be installed. This improves energy efficiency as well as power output and brings in a lot of efficiencies. GIS data equally plays an important role. It includes geographical information data from satellite data or LIDAR (light detection and ranging) that helps in spatial (three dimensional) planning.
4) *Asset management:* The industry has asset-intensive units. Companies regularly face a lot of asset management-related challenges; for example, asset operations, asset monitoring, sharing of resources, asset maintenance, asset procurement, inventory management, etc. Efficiency can be achieved utility companies based on insights drawn from the analytics.
5) *Energy efficiency:* Data driven from smart meters, asset operations, business policies, and weather data can be integrated and analyzed over a period of time which helps in designing electrical devices with energy-efficiency parameters, thus reducing power requirements. Energy efficiency plays an important role to reduce carbon emissions. This also includes various other issues like equipment efficiency issues and problems in insulation, as well as improvements in operational areas. Forecasting of energy consumption and prediction energy savings can be done in this way by the companies.
6) *Job Opportunities:* With more interest and investment in the Big Data technologies, the professionals carrying the skills of big data analytics are in huge demand. The organizations pay attractive incentives and packages for qualified professionals. The professionals like engineers and data administrators can learn the analytics tools for a promising career. The nature of the job differs in different domains of industry and so does the requirement of the industry. Emerging of analytics in every field has made the workforce needs equally enormous the job titles are Big Data Analyst, Big Data Engineer, Business Intelligence Consultants, Solution Architect, etc. Moreover, some certifications can help in showcasing of talent and skills. Provision you an edge over others can be done by knowledge and experience of Big Data analytics. During job search also, it can open new opportunities for you.

B. Limitations of Big Data in Energy Intensive Manufacturing Industries

The proposed framework and key enabling technologies for energy big data analytics provide a new kind of infrastructure to improve energy efficiency in the whole production process. However, the soft sensor technologies are only proposed in architecture, lacking implementation in detail. In addition, energy data mining models should be studied deeply integrating energy consumption analysis and data mining. Future research can be carried out in the following aspects. Firstly, how to use the soft sensor approaches to capture real-time energy data in harsh production environment. Secondly, by using the data mining theory, a mathematical model will be established to identify the hidden knowledge and rules from the multi-source and heterogeneous energy big data. For example, how to establish a quantitative model such as state space equations and real-time distributed control for energy efficient manufacturing systems.

C. Applications of Big Data in Energy Intensive Manufacturing Industries

The Energy Intensive Industries are the industries most affected by big data trends and possibilities due to the nature and amount of data that is produced by it. Discovering the potentials of using big data tools are just started by most manufacturers, but there are already some pioneers within the biggest manufacturers who have provided some big data uses cases to follow. Increase in Demand for natural resources like oil, agricultural products, minerals, gas, metals, and so on, this had led to an increase in the volume, complexity, and velocity of data that is a challenge to handle. Similarly, large volumes of data from the energy intensive industry are untapped. The underutilization of this information prevents the improved quality of products, energy efficiency, reliability, and better profit margins. In the natural resources industry, big data allows for predictive modelling to support decision making that has been utilized for ingesting and integrating large amounts of data from geospatial data, graphical data, text, and temporal data. To solve today’s manufacturing challenges and to gain a competitive advantage, among other benefits can be done through Big Data.

IV. CASE STUDY

A. Big Data Analytics applied at energy Management in Energy Sector

The Case Study proposes a data analytic model for IOT, in order to integrate the data collected from different sources and to make decision about energy awareness at production line and machine level. Improvement about overall equipment effectiveness of machine tools which will improve resource efficiency and productivity in manufacturing and support the development of small factories and to deploy further insights about energy consumption profiles and patterns by applying different data analysis techniques like clustering and predictive analysis techniques.

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1) *Inferences:* The above Case Study explains the scenario for managing use of energy at energy related industries by making the best use of Big Data techniques to maintain energy level at machine and production stages [15].

B. Big Data Analytics Throughout Product lifecycle to Support Sustainable Smart Manufacturing

The Case Study introduces the combination of key technologies of SM with the concept of ubiquitous servitization at all lifecycle stages for intelligent and sustainable production and the concepts of big data and data classification criteria, system architectures, key technologies of SM, and applications of BDA in SM were characterized in detail and also a conceptual framework of BDA in SSM was proposed with the potential applications and key advantages of BDA in SSM.

1) *Inferences:* The above Case Study introduces the concept of big data analytics in Smart Manufacturing and sustainable Manufacturing with detailed information of efficient use of energy which is one of the main tools to prevent energy consumption growth without compromising on the customer's requirements by enabling data driven decision making in organizations for Sustainable and Cleaner Production [1].

V. CONCLUSION AND FUTURE SCOPE

As global energy needs are continuously growing. Hence, the conventional methods for producing more energy to meet the demand pose a great threat to the environment. Among other solutions, energy efficiency has become a major tool for minimizing the need for producing more energy to cater for the growing demand. Inherently, the cause of improving energy efficiency relies on understanding the usage patterns, identifying the problematic areas, establishing good energy consumption practices and to analyzing the faults to reduce energy leakages. The advancement in sensors, ubiquitous computing and communication technologies has provided the basis for effectively collecting the usage data to understand energy usage. All of these data features refer to application of Big Data technologies for energy efficiency. Therefore, in future distributed parallel computing programming models used are: MapReduce provide the basic environment for handling Big Data. The power of MapReduce using Apache Hadoop ecosystem tools to present an end-to-end Big Data analytics tool. Hadoop supports scalability to meet large volumes of data sets while the there are other tools that can integrate with Hadoop to process complexity in data. Hence, it is necessary to incorporate a priori knowledge of plants and processes in order to achieve successful applications, which leaves both challenges and opportunities for future research. Some of the Big Data Platforms and Big Data softwares like: Google Big Query, Google Big Data, SAP Big Data Analytics, Teradata Big Data Analytics, Good Data, etc. can be used. The big data analytics market in energy sector is expected to grow at a CAGR of 10.22%, during the period of 2019 – 2024. This study contributes to the enhancement of people's understanding about energy consumption behaviour, the development of more effective intervention strategies, as well as the achievement of long-term energy conservation and sustainable development.

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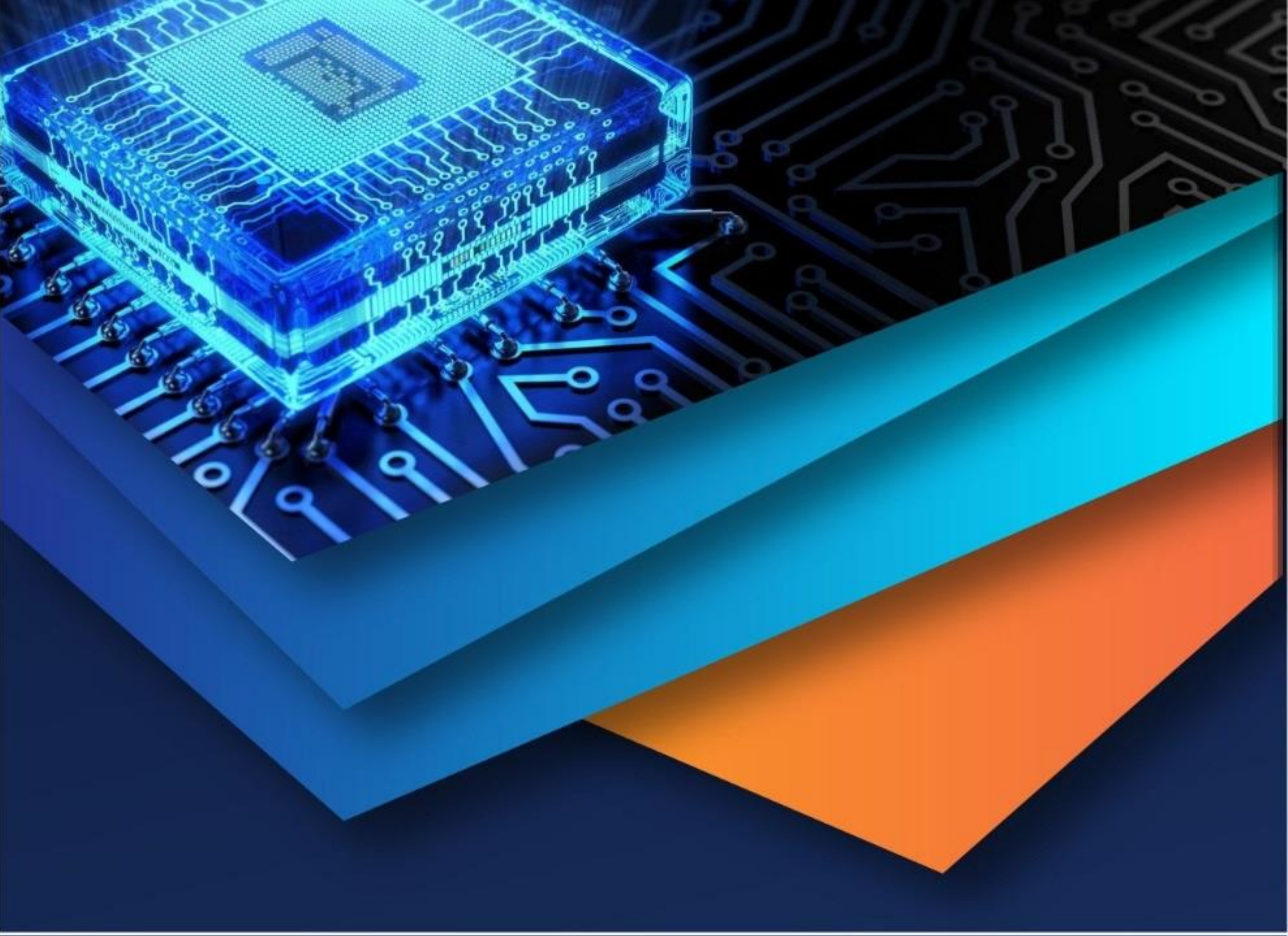

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