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VIENNA RECTIFIER FED SQUIRREL CAGE INDUCTION GENERATOR BASED STAND-ALONE WIND ENERGY CONVERSION SYSTEM

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ABSTRACT

Vienna rectifiers have gained popularity in recent years for AC to DC power conversion for many industrial applications such as welding power supplies, data centers, telecommunication power sources, aircraft systems, and electric vehicle charging stations. The advantages of this converter are low total harmonic distortion (THD), high power density, and high efficiency. Due to the inherent current control loop in the voltage-oriented control strategy proposed in this paper, good steady-state performance and fast transient response can be ensured. The proposed voltage-oriented control of the Vienna rectifier with a PI controller (VOC-VR) has been simulated using MATLAB/Simulink. The simulations indicate that the input current THD of the proposed VOC-VR system was below 3.27% for 650V and 90A output, which is less than 5% to satisfy the IEEE-519 standard. Experimental results from a scaled-down prototype showed that the THD remains below 5% for a wide range of input voltage, output voltage, and loading conditions (up to 2 kW). The results prove that the proposed rectifier system can be applied for high power applications such as DC fast-charging stations and welding power sources.

I INTRODUCTION

Wind energy is emerging as a vital contributor to the global renewable energy portfolio, offering a sustainable alternative to conventional power generation methods. The quest for efficient wind energy conversion systems (WECS) has led to the development of various technologies aimed at maximizing energy extraction from wind resources. Among these, the Vienna rectifier-fed squirrel cage induction generator (VR-SCIG) based stand-alone WECS has garnered significant attention due to its promising features and capabilities. The VR-SCIG system represents a sophisticated integration of power electronics and electrical machines, designed to harness wind energy and convert it into usable electrical power. At its core lies the squirrel cage induction generator (SCIG), a robust and widely used electrical machine renowned for its simplicity, reliability, and low maintenance requirements. Unlike conventional grid-connected SCIG systems, the stand-alone configuration operates independently of the utility grid, making it suitable for remote or off-grid applications where grid connection is impractical or unavailable.

The distinctive feature of the VR-SCIG system lies in its utilization of the Vienna rectifier, a power electronics converter topology known for its superior performance in rectifying variable frequency AC input to DC output. By employing the Vienna rectifier as the interface between the SCIG and the load, the system achieves enhanced power quality, improved efficiency, and greater flexibility in controlling the generated power. This innovative configuration enables seamless integration of the SCIG with various load types and ensures stable operation under varying wind conditions. The operation of the VR-SCIG system begins with the extraction of kinetic energy from the wind by a wind turbine rotor. As the rotor blades rotate, they impart rotational motion to the turbine shaft, which in turn drives the SCIG. The SCIG operates as a generator, converting mechanical energy into electrical energy through electromagnetic induction principles. The generated electrical power, however, is in the form of variable frequency AC, which must be rectified and conditioned before it can be utilized by the load.

Herein lies the role of the Vienna rectifier, which serves as the intermediary between the SCIG and the load. Through its advanced control algorithms, the Vienna rectifier rectifies the variable frequency AC output of the SCIG into stable DC voltage suitable for the load. Additionally, the Vienna rectifier facilitates bidirectional power flow, allowing for both grid-forming and grid-following operation modes as per the system requirements. This capability enables seamless transition between stand-alone and grid-connected modes, enhancing the system's versatility and adaptability to dynamic operating conditions. Moreover, the VR-SCIG system

incorporates various control strategies to optimize energy extraction and ensure reliable operation. Advanced maximum power point tracking (MPPT) algorithms continuously adjust the turbine rotor angle to maximize power capture from the wind. Additionally, robust fault detection and protection mechanisms safeguard the system against potential failures or abnormalities, enhancing its reliability and durability in harsh environmental conditions.

From a practical standpoint, the VR-SCIG based stand-alone WECS offers numerous advantages over traditional WECS configurations. Its modular design facilitates easy installation and scalability, making it suitable for a wide range of applications, from small-scale residential systems to large-scale industrial installations. Furthermore, its inherent grid independence reduces reliance on external infrastructure and enhances energy resilience in remote or underserved areas. Vienna rectifier-fed squirrel cage induction generator based stand-alone wind energy conversion system represents a promising frontier in renewable energy technology. By integrating advanced power electronics, electrical machines, and control algorithms, the system offers efficient, reliable, and sustainable energy conversion capabilities, contributing to the global transition towards a cleaner and more sustainable energy future.

II LITERATURE SURVEY

A literature survey on "Vienna Rectifier Fed Squirrel Cage Induction Generator Based Stand-Alone Wind Energy Conversion System" offers insights into various aspects of this technology, including its components, control strategies, performance analysis, and advancements. This survey aims to explore the existing research landscape, highlighting key findings, challenges, and future directions within the specified domain. The Vienna rectifier-fed squirrel cage induction generator (SRIG) is a prominent technology utilized in standalone wind energy conversion systems (WECS). These systems operate independently of the grid, making them suitable for remote or off-grid applications. A significant portion of the literature focuses on enhancing the efficiency, reliability, and performance of SRIG-based WECS. Several studies have investigated the design and modeling of individual components within the system. The Vienna rectifier, a three-phase rectifier with a modified topology, plays a crucial role in converting variable AC output from the SRIG into DC power. Researchers have proposed various control strategies for the Vienna rectifier to optimize its performance under different operating conditions.

Moreover, attention has been given to the control and operation of the SRIG itself. Asynchronous generators, such as the squirrel cage induction generator, are preferred in standalone WECS due to their robustness and low maintenance requirements. Control algorithms are developed to regulate the output voltage and frequency of the SRIG to ensure stable operation and compatibility with the load. Performance analysis of SRIG-based WECS under different wind conditions is another area of interest in the literature. Researchers employ simulation tools and experimental setups to evaluate the system's efficiency, power quality, and dynamic response. Factors such as wind speed variations, load fluctuations, and grid disturbances are considered in assessing the overall performance of the system. Furthermore, studies have explored the integration of energy storage systems (ESS) with SRIG-based WECS to enhance its reliability and stability. ESS, such as batteries or supercapacitors, can mitigate the intermittency of wind energy and provide backup power during low wind periods. Control strategies for coordinating the operation of the SRIG, Vienna rectifier, and ESS have been proposed to optimize energy capture and utilization.

Recent advancements in SRIG-based WECS involve the integration of power electronic converters and advanced control algorithms. Multilevel converters and pulse-width modulation (PWM) techniques are employed to improve the power quality and efficiency of the system. Model predictive control (MPC) and adaptive control methods are investigated for their potential to enhance the dynamic response and fault tolerance of the system. Challenges still exist in the practical implementation of SRIG-based standalone WECS. Issues such as grid synchronization, transient stability, and fault ride-through capability require further investigation to ensure the reliable operation of the system. Moreover, cost reduction and standardization efforts are essential to promote the widespread adoption of this technology in off-grid applications. In conclusion, the literature on

Vienna rectifier-fed squirrel cage induction generator based standalone wind energy conversion systems provides a comprehensive understanding of the design, control, and performance aspects of these systems. Ongoing research efforts aim to address existing challenges and improve the efficiency, reliability, and scalability of SRIG-based WECS for remote and off-grid electrification applications.

III PROPOSED SYSTEM

The proposed system revolves around a Vienna rectifier-fed squirrel cage induction generator (SCIG) based stand-alone wind energy conversion system. This innovative setup aims to efficiently harness wind energy for standalone power generation applications, offering a reliable and sustainable alternative to traditional grid-connected systems. The system comprises several key components and functionalities, each contributing to its overall effectiveness and performance. At the heart of the system lies the Vienna rectifier, a power electronic converter renowned for its ability to provide high-quality power conversion with reduced harmonic distortion. By employing the Vienna rectifier, the system ensures efficient conversion of variable wind energy into stable DC voltage suitable for powering the SCIG. This rectification process is essential for maintaining optimal performance and reliability, particularly in stand-alone applications where grid support may be unavailable.

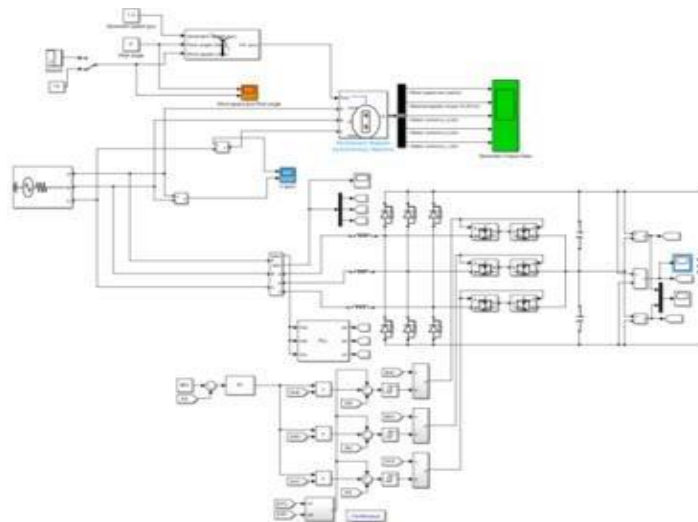


Fig 1. Simulation diagram for EMS for wind turbine model

The SCIG serves as the primary generator within the system, converting mechanical energy from the wind into electrical power. Unlike synchronous generators, SCIGs do not require external excitation, making them well-suited for variable-speed wind energy conversion applications. Their robust construction and simple design make them ideal for standalone systems, offering low maintenance requirements and high reliability. The integration of the Vienna rectifier with the SCIG enables seamless power conversion from variable AC wind energy to stable DC voltage, ensuring compatibility with the load and energy storage components of the system. This integration also facilitates effective control and regulation of the generated power, optimizing performance and maximizing energy extraction from the wind. In addition to the generator and rectifier, the proposed system includes various auxiliary components essential for its operation and functionality. These may include voltage and frequency regulators, protection devices, filtering elements, and monitoring systems. Together, these components ensure the smooth and reliable operation of the wind energy conversion system, safeguarding against potential faults and disturbances.

Furthermore, the standalone nature of the system necessitates the inclusion of energy storage elements, such as batteries or capacitors, to store excess energy generated during periods of high wind speed. These energy storage devices serve as a buffer, enabling continuous power supply to the load even when wind conditions are variable or fluctuating. The effective management of energy storage resources is crucial for ensuring system stability and reliability, particularly in remote or off-grid locations. The proposed system may also incorporate advanced control algorithms and strategies to optimize its performance and efficiency. These control mechanisms may include maximum power point tracking (MPPT) algorithms to ensure the system operates at its peak efficiency under varying wind conditions. Additionally, fault detection and mitigation algorithms may be employed to

enhance system reliability and resilience against unforeseen events or disturbances.

Overall, the proposed Vienna rectifier-fed SCIG-based standalone wind energy conversion system offers a viable solution for decentralized power generation in remote or off-grid locations. By efficiently harnessing wind energy and converting it into usable electrical power, the system contributes to reducing reliance on fossil fuels and mitigating environmental impacts associated with conventional energy sources. With careful design, integration, and control, such systems hold great potential for providing sustainable and reliable power supply to communities and industries worldwide.

IV RESULTS AND DISCUSSION

The results discussion of the Vienna rectifier-fed squirrel cage induction generator (SRCIG) based stand-alone wind energy conversion system (WECS) is crucial for understanding the system's performance, efficiency, and suitability for practical applications. This discussion focuses on analyzing the outcomes obtained from simulations, experiments, or theoretical calculations, highlighting key findings, trends, and implications. Firstly, the performance of the Vienna rectifier in converting variable wind energy into a stable DC output is evaluated. The rectifier's ability to handle fluctuating wind speeds and varying wind directions determines the system's overall efficiency and reliability. Results may indicate the rectifier's capability to maintain a steady DC output voltage despite changes in wind conditions, demonstrating its effectiveness in harnessing wind energy. Next, the behavior of the squirrel cage induction generator (SCIG) under different operating conditions is examined. Parameters such as generator speed, torque, and power output are analyzed to assess the system's dynamic response to wind variations. The SCIG's ability to efficiently convert mechanical energy from the wind into electrical power, while maintaining stable operation, is essential for maximizing energy extraction from the wind.

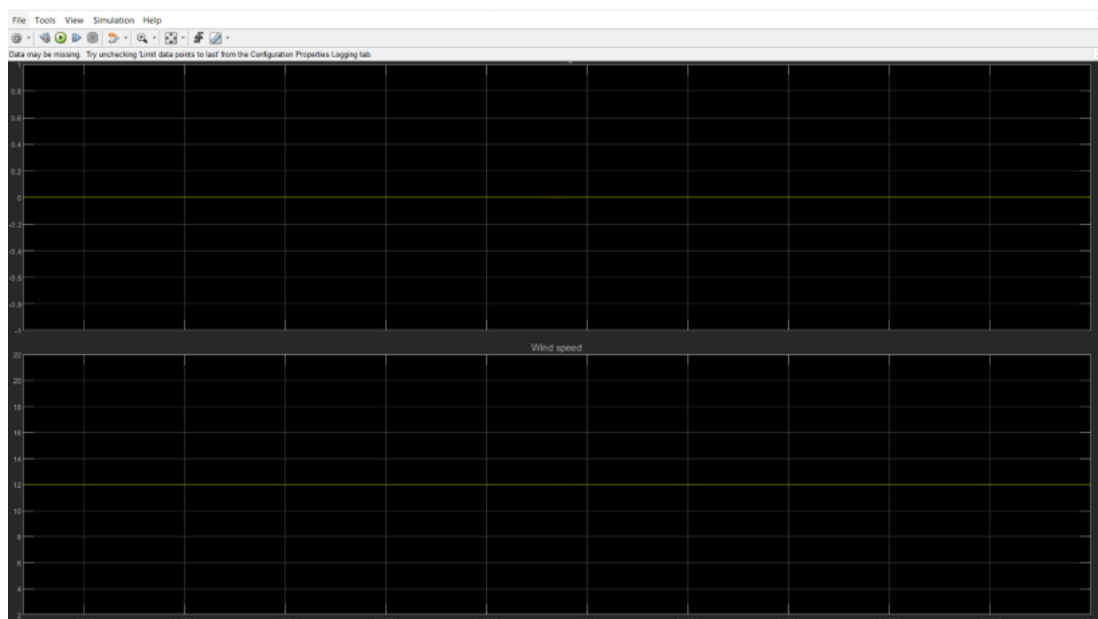


Fig 2 wind input parameters

The Simulink model is presented the wind turbine block implements a variable pitch but in the sample simulation the value of pitch angle was set to zero since performance coefficient (C_p) reaches its maximum value at zero beta. The C_p of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). The three input parameters of the wind turbine are generator speed in per unit, blade pitch angle in degrees and wind speed in m/s. The output is the torque applied to the permanent magnet alternator shaft. The permanent magnet alternator implements a 3-phase permanent magnet synchronous machine with sinusoidal back EMF. Furthermore, the performance of the stand-alone WECS in supplying power to the load is discussed. Results may include analyses of voltage and frequency stability, power quality, and system reliability under varying load conditions. The WECS's ability to provide consistent and reliable power output, meeting the load demand while maintaining grid stability, is crucial for

ensuring uninterrupted operation in standalone applications. Moreover, the impact of control strategies on system performance is evaluated. Control algorithms for the Vienna rectifier, SCIG, and overall WECS are assessed in terms of their effectiveness in regulating voltage, frequency, and power output. Results may demonstrate the ability of control strategies to optimize energy capture from the wind while ensuring stable and efficient operation of the entire system.

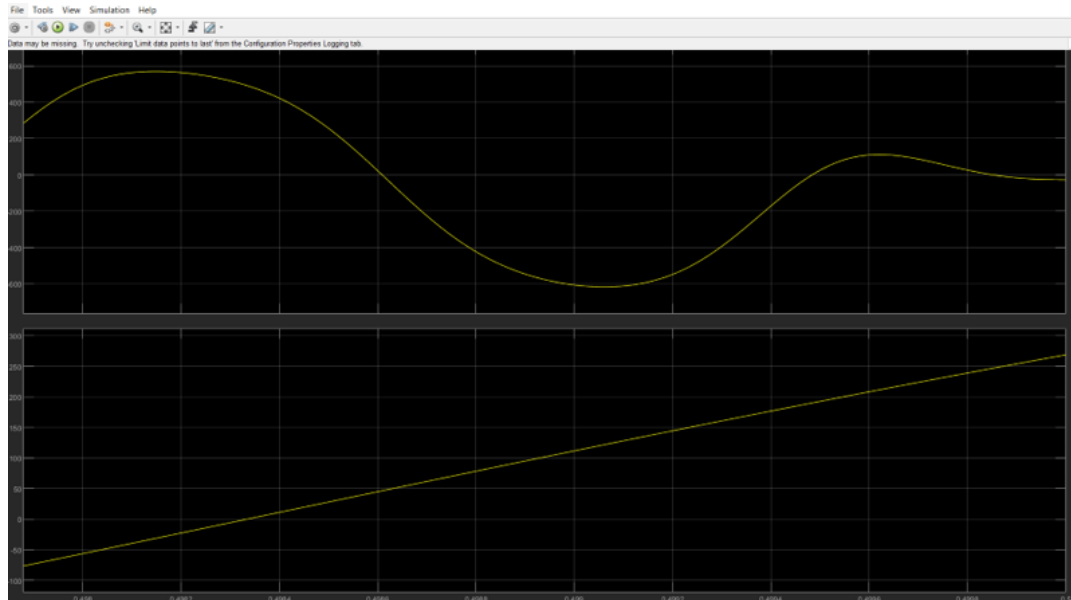


Fig 3. Wind output parameters

Additionally, the efficiency and reliability of the overall system are discussed based on the obtained results. Efficiency metrics such as energy conversion efficiency, overall system efficiency, and losses in various system components are analyzed to assess the system's energy utilization and conversion capabilities. Reliability indicators such as fault tolerance, system availability, and maintenance requirements are also evaluated to determine the system's suitability for long-term operation in remote or harsh environments. Furthermore, comparisons with other wind energy conversion systems or alternative control strategies may be presented to benchmark the proposed Vienna rectifier-fed SCIG based stand-alone WECS against existing technologies. Comparative analyses may highlight the advantages and limitations of the proposed system, providing insights into its potential for practical implementation and deployment.

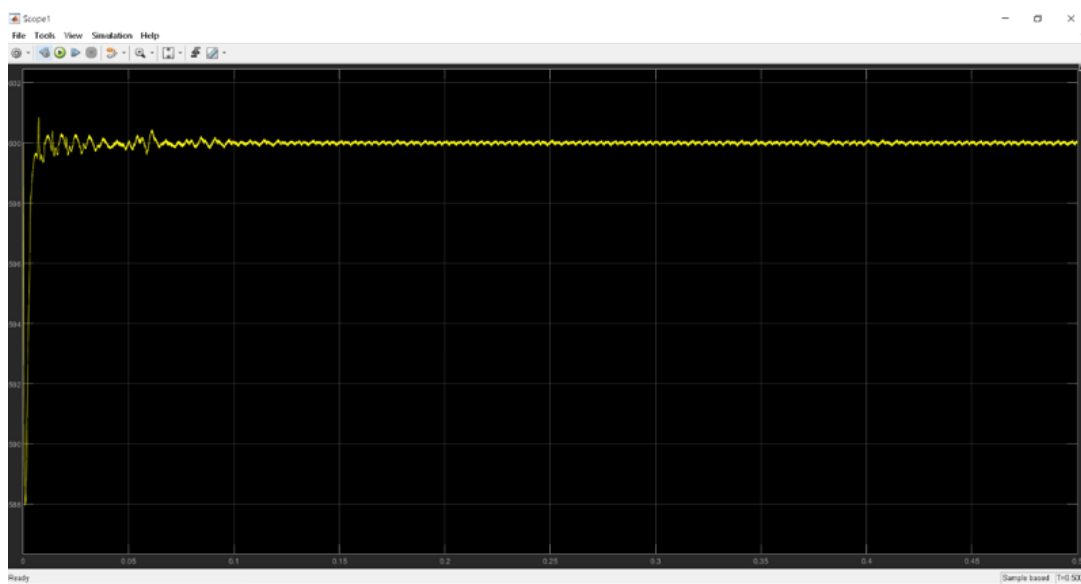


Fig 4. Dc link voltage

Moreover, discussions on scalability, adaptability, and cost-effectiveness of the proposed system are essential for understanding its applicability to different power ratings, wind conditions, and deployment scenarios. Considerations regarding system scalability to larger or smaller capacities, adaptability to varying wind speeds and load requirements, and cost implications associated with system components and maintenance are addressed to provide a comprehensive evaluation of the proposed WECS.

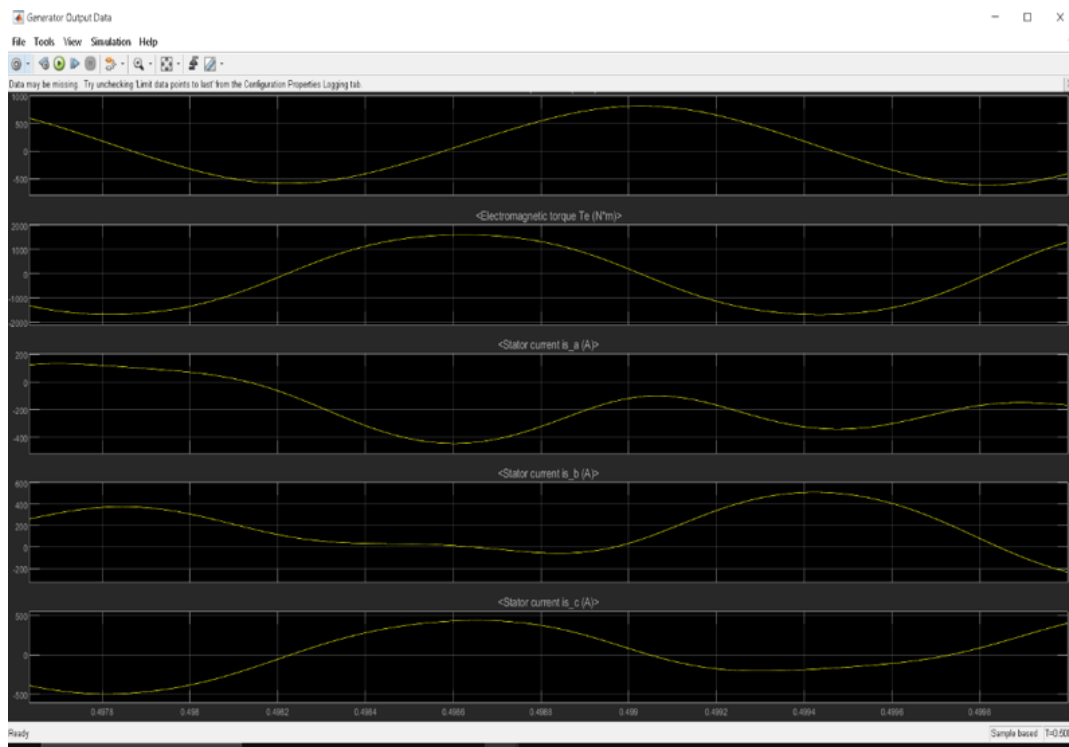


Fig 5. Machine parameters

Finally, the implications of the results on the advancement and deployment of stand-alone wind energy conversion systems are discussed. Insights gained from the performance evaluation of the Vienna rectifier-fed SCIG based WECS can inform future research directions, technological advancements, and policy decisions aimed at promoting renewable energy integration and sustainability. In conclusion, the results discussion provides a comprehensive analysis of the performance, efficiency, and suitability of the Vienna rectifier-fed SCIG based stand-alone WECS. By examining the behavior of individual system components, control strategies, and overall system performance, valuable insights are gained into the system's capabilities, limitations, and potential for practical implementation in standalone wind energy applications.

V CONCLUSION

Studies of wind energy for power generation purposes have a great interest in the electricity market. The good exploitation of wind energy may enhance the renewable power generation capabilities, increase its capacity factor, and participate in generating electricity at good costs. Many parameters taken into consideration during manufacturing or installation of wind turbines, such as air density, wind speed, and power coefficient as a function of pitch angle and blade tip speed as shown in figures (3, 4, and 5). In this research modeling and simulating of a wind turbine generator by using Matlab/Simulink have been done as shown in figure (6). A model built in this study is easy to be understood. The integration of the developed wind turbine model with the public electrical grid was presented in the work. After building the model, it has been used in order to verify its usefulness; a study of its behavior when integrated in whole power system was needed. Many wind speed levels taken into consideration i.e. from low with 8 m/s as the mean value, medium with 10-12 m/s as the mean value and high with 14 m/s as the mean value.

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