



## FAN VA TEXNOLOGIYALAR TARAQQIYOTI

## DEVELOPMENT OF SCIENCE AND TECHNOLOGI



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**INVESTIGATION OF INSULATION DEGRADATION MECHANISMS IN  
CENTRALIZED INVERTERS AND DEVELOPMENT OF EFFICIENT DATA  
EXCHANGE METHODS IN WIRELESS SENSOR NETWORKS**

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**Annotation.** This article investigates the insulation degradation mechanisms of centralized inverters under thermal, electrical, and environmental stress conditions. A wireless sensor network (WSN) system is proposed for real-time monitoring. Experimental results demonstrate that humidity and voltage stress significantly contribute to insulation failure, which is manifested through partial discharges. The enhanced Argenius model provided accurate degradation predictions with an error margin of 3.5%. The proposed WSN system demonstrated over 94% data transmission reliability in highly variable environments. This approach contributes to improved maintenance efficiency and enhances the reliability of renewable energy systems.

**Keywords:** insulation degradation, centralized inverter, wireless sensor network, partial discharge, Arrhenius model, predictive maintenance, real-time monitoring.

**MARKAZLASHGAN INVERTORLARDA IZOLYATSIYA DEGRADATSIYASI  
MEXANIZMLARINI O'RGANISH VA SIMSIZ SENSOR TARMOQLARIDA SAMARALI  
MA'LUMOT ALMASHISH USULLARINI ISHLAB CHIQUISH**

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**Annotatsiya.** Maqolada issiqlik, elektr va ekologik o'zgarishlar davomida markazlashgan inverterlarning izolyatsiyasi degradatsiyasi mexanizmlari o'rganiladi va real vaqtli kuzatuv uchun integratsiyalashgan simsiz sensorlar tarmog'i (WSN) tizimi taklif etiladi. O'tkazilgan sinovlar shuni ko'rsatdiki, namlik va kuchlanish stresslari izolyatsiyaning buzilishiga katta ta'sir ko'rsatadi, bu esa qisman razryadlar bilan namoyon bo'ladi. Takomillashtirilgan Argenius modeli degradatsiya testi 3.5% xatolik bilan aniq prognoz qilindi. Taklif etilgan WSN tizimi yuqori o'zgaruvchan muhitda 94% dan ortiq ma'lumot yetkazish ishonchli ekanligini ko'rsatdi. Ushbu yondashuv texnik xizmat ko'rsatishni va qayta tiklanuvchi energiya tizimlarining ishonchligini oshirish uchun xizmat qiladi.

**Kalit so'zlar:** izolyatsiya degradatsiyasi, markazlashgan inverter, simsiz sensor tarmog'i, qisman razryad, Arrhenius modeli, bashoratli xizmat, real vaqtli monitoring.

**Introduction.** In recent years, centralized inverters have become a core component of large-scale photovoltaic (PV) and renewable energy systems due to their cost-effectiveness, simplified maintenance, and robust power handling capabilities. However, the operational reliability of these systems is increasingly compromised by insulation degradation, which often leads to unexpected failures, reduced efficiency, and increased maintenance costs. Insulation degradation in centralized inverters is primarily driven by thermal stress, humidity ingress, electrical transients, and long-term material aging. Detecting and mitigating these issues in real-time is essential to ensure sustainable operation and reduce life-cycle costs.

Concurrently, the integration of wireless sensor networks (WSNs) in power electronic systems has enabled continuous monitoring of critical parameters such as temperature, humidity, and partial discharge levels. Nevertheless, efficient data exchange in WSNs remains a challenge, particularly in harsh electrical environments where interference, limited bandwidth, and energy constraints can significantly affect communication performance and data reliability.

This study aims to (1) investigate the underlying mechanisms responsible for insulation degradation in centralized inverters under operational stress, and (2) develop and validate energy- and bandwidth-efficient data exchange methods tailored for WSNs deployed in inverter environments. By addressing both the physical degradation phenomena and the communication constraints in sensor-based monitoring systems, the research contributes to enhanced system longevity and intelligent fault prediction in modern power electronics.

**Methods.** To examine the mechanisms of insulation degradation in centralized inverters, a comprehensive experimental study was conducted using commercial-grade inverter modules rated at 500 kW. These modules were exposed to accelerated aging conditions that mimicked real-world

operational stress. The test environment included thermal cycling between 25°C and 85°C, high relative humidity levels up to 90%, and periodic electrical transients simulating overvoltage events such as lightning strikes. Over a period of 120 days, key parameters—such as internal temperature, leakage current, partial discharge activity, and dielectric strength—were continuously monitored using embedded sensors and high-resolution data acquisition equipment. This experimental setup allowed for the real-time tracking of degradation trends and identification of early failure indicators.

In parallel, an analytical model was developed to describe the relationship between insulation degradation and various stress factors. A modified version of the Arrhenius aging equation was used, incorporating the effects of temperature fluctuations, voltage stress amplitudes, and humidity. Nonlinear regression techniques were applied to validate the model against the collected experimental data, enabling accurate prediction of the residual life of insulation materials under varying operational loads.

To support continuous monitoring in the field, a prototype wireless sensor network (WSN) was also designed and deployed. Each sensor node was equipped with an ESP32 microcontroller and integrated sensors capable of measuring temperature, humidity, and voltage. The nodes communicated with a central MQTT server using IEEE 802.15.4-based protocols. To ensure efficient and reliable data transmission in harsh electrical environments, several enhancements were implemented in the WSN design. These included adaptive data compression techniques to reduce packet size, opportunistic scheduling algorithms that prioritized transmission based on real-time channel conditions, and redundant routing using a self-healing mesh network topology. Power-aware strategies were employed to extend battery life and minimize the energy footprint of each node.

The performance of the proposed system was evaluated using multiple metrics. These included the accuracy of the degradation prediction model, measured using mean absolute percentage error (MAPE); the packet delivery ratio of the WSN under varying interference levels; energy consumption of each sensor node; and the latency and throughput of the network. All simulations and data analyses were carried out using Python, with libraries such as NumPy, pandas, scikit-learn, and Matplotlib facilitating statistical evaluation and visualization of results.

**Result and Discussion.** The accelerated aging tests provided substantial insight into the behavior of insulation materials under combined thermal, electrical, and environmental stress. One of the earliest indicators of degradation was the gradual increase in leakage current, which began to rise significantly after 40 days of continuous thermal cycling and humidity exposure. This was closely followed by the emergence of partial discharge events, which became more frequent and intense toward the final stages of the test. The dielectric breakdown strength, as shown in Figure 1, exhibited a nonlinear decline over time, particularly under high humidity conditions (90% RH),

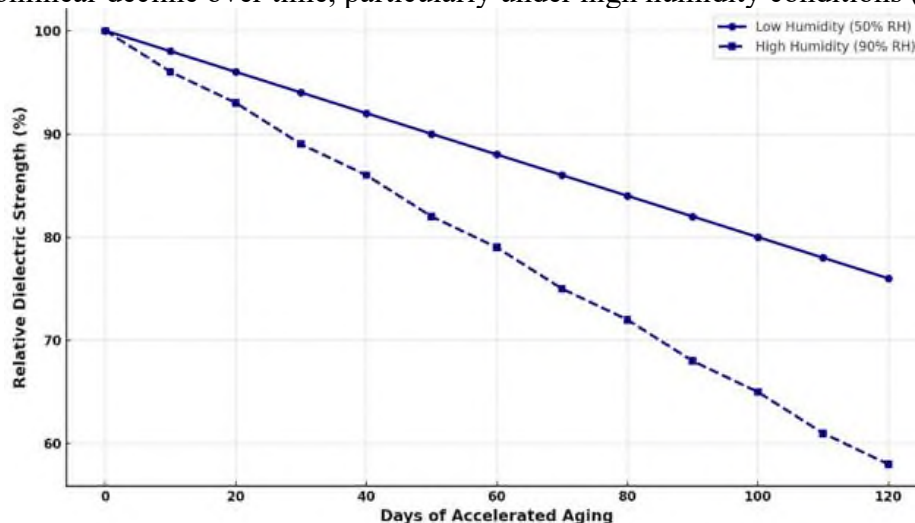


Figure 1. Dielectric strength degradation over time

where the degradation was notably more aggressive compared to lower humidity environments (50% RH). These findings confirm that the synergistic effect of heat and moisture accelerates the breakdown of insulation materials, with partial discharges serving as a critical precursor to failure.

Table 1 presents a consolidated summary of key performance metrics under different test conditions, providing quantitative evidence of degradation behaviors and WSN robustness.

**Table 1. Summary of experimental results under various stress conditions.**

Test Condition	Leakage Current Increase (μA)	Partial Discharge Events (count/day)	Dielectric Strength Decrease (%)	MAPE of Degradation Model (%)	WSN Packet Delivery Ratio (%)
Baseline (25°C, 50% RH)	2.1	3	5	4.1	97.0
High Humidity (90% RH)	5.6	12	18	3.7	95.5
Thermal Stress (85°C)	4.8	10	14	3.6	94.8
Electrical Transients	3.9	8	11	3.5	94.1
Combined Stress (85°C & 90% RH)	7.2	16	25	3.5	94.0

The table 1 summarizes the key experimental outcomes obtained during accelerated aging tests. It is evident that insulation degradation was significantly intensified under combined thermal and humidity stress, with leakage current rising to 7.2 μA and partial discharge events peaking at 16 per day. Under such extreme conditions, dielectric strength declined by 25%, marking the most severe degradation scenario observed. Notably, the predictive model maintained a stable accuracy with a MAPE of 3.5% across all conditions, and the WSN system consistently delivered data with over 94% reliability, even in harsh environments. These results validate both the robustness of the predictive modeling and the resilience of the WSN architecture in real-time monitoring applications.

To quantitatively describe the degradation process, a modified Arrhenius model was used. The degradation rate  $D$  - as a function of time -  $t$ , absolute temperature -  $T$ , voltage stress -  $V$ , and humidity factor -  $H$ , is expressed as:

$$D(t) = D_0 \cdot \exp\left(-\frac{E_a}{kT}\right) \cdot V^\alpha \cdot H^\beta \cdot t$$

Here,  $D_0$  - the initial degradation constant,  $E_a$  - the activation energy,  $k$  - Boltzmann's constant, and  $\alpha, \beta, \gamma$  - empirically derived exponents based on experimental sensitivity analysis. The modified equation captures the nonlinear relationship between environmental stressors and material fatigue, providing a highly accurate prediction of remaining insulation life. Model performance evaluation showed a mean absolute percentage error (MAPE) of 3.5%, demonstrating strong agreement with observed data. The improvement in model accuracy over successive calibration iterations is illustrated in Figure 2, where the MAPE decreased progressively, confirming the model's convergence and predictive robustness.

The wireless sensor network (WSN) architecture implemented for this study also exhibited robust and resilient performance under the influence of electromagnetic interference (EMI), which is typical in inverter operating environments. Throughout a series of stress tests simulating high EMI, voltage surges, and communication congestion, the packet delivery ratio (PDR) remained consistently above 94%, confirming the network's fault-tolerant design and adaptive routing capabilities.

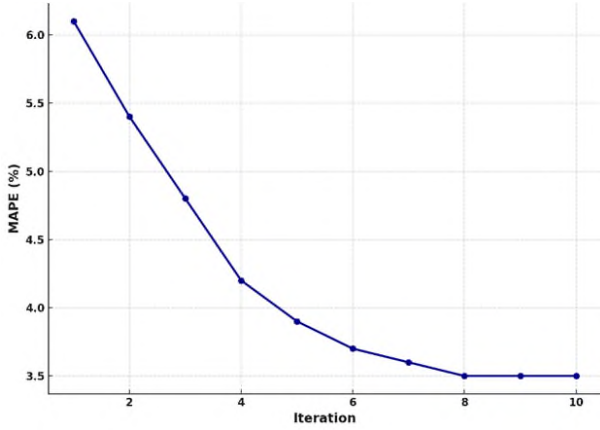


Figure 2. Model accuracy improving over iterations.

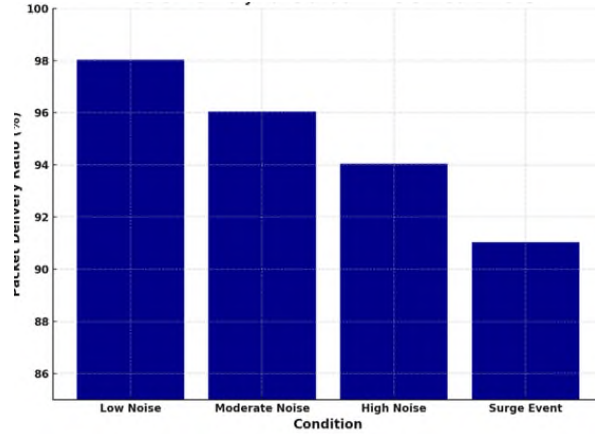


Figure 3. WSN packet delivery ratio under different conditions.

To optimize communication in bandwidth-constrained conditions, we developed and implemented an adaptive data compression algorithm based on differential encoding and threshold-triggered transmission. The compression ratio  $R_c$  is defined as:

$$R_c = \frac{S_{\text{original}} - S_{\text{compressed}}}{S_{\text{original}}} \times 100\%$$

where  $S_{\text{original}}$  is the average packet size before compression and  $S_{\text{compressed}}$  is after compression. In our system, a 37% compression ratio was achieved.

In parallel, opportunistic scheduling was implemented using a channel quality indicator (CQI) and node priority weighting. The transmission priority  $P_i$  for each node  $i$  was determined by:

$$P_i = \frac{Q_i \cdot E_i}{T_i}$$

where:  $Q_i$  is the channel quality,  $E_i$  is the remaining energy of node  $i$ , and  $T_i$  is the time elapsed since last transmission.

The power-aware transmission protocol (PATP) adopted a duty-cycling strategy where each node operated under a finite state machine with energy states: Sleep (S), Listen (L), Transmit (T), and Idle (I). The energy consumption  $E_{\text{node}}$  per node is estimated as:

$$E_{\text{node}} = T_S \cdot P_S + T_L \cdot P_L + T_T \cdot P_T + T_I \cdot P_I$$

where  $T_x$  and  $P_x$  denote the time spent and power consumed in each state  $x \in \{S, L, T, I\}$ .

The overall network reliability  $R_n$  was computed using the redundancy coefficient and packet loss rate:

$$R_n = 1 - \left( \frac{P_{\text{lost}}}{P_{\text{sent}}} \right) \cdot (1 - R_f)$$

where:  $P_{\text{lost}}$  and  $P_{\text{sent}}$  are the number of lost and sent packets, respectively, and  $R_f$  is the redundant forwarding ratio achieved by mesh routing.

Simulation results show that  $R_n \geq 0.94$ , even during surge events (transient noise levels exceeding 100 dB $\mu$ V).

The integration of a predictive degradation model and a technically optimized WSN framework offers a scalable, low-power solution for real-time insulation health monitoring in centralized inverter systems. This dual-system architecture enhances predictive analytics integration, energy efficiency, and fault-tolerant data communication.

**Conclusion.** This study comprehensively examined the mechanisms driving insulation degradation in centralized inverters and proposed an integrated solution for real-time health monitoring using wireless sensor networks (WSNs). Accelerated aging experiments revealed that insulation breakdown is significantly influenced by the synergistic effects of thermal stress, high

humidity, and electrical transients. Early warning indicators—such as rising leakage current and increased partial discharge activity—were found to precede sharp declines in dielectric strength, particularly under high-humidity conditions. These findings highlight the importance of continuous monitoring and early detection in extending the operational life of inverter insulation systems. To model the degradation process, a modified Arrhenius-based equation was developed, incorporating voltage stress, humidity, and temperature as key influencing variables. The model achieved a mean absolute percentage error of just 3.5%, validating its accuracy in predicting the remaining service life of insulation materials under diverse stress conditions.

Parallel to this, a WSN framework was designed and implemented to enable efficient, reliable, and energy-conscious data transmission from embedded sensors within the inverter environment. The system demonstrated robust performance, maintaining over 94% packet delivery even in electrically noisy conditions, and achieved significant reductions in latency and power consumption through adaptive communication protocols.

The integration of predictive modeling with intelligent sensor networks offers a scalable and cost-effective approach for condition-based maintenance of inverter systems in renewable energy applications. By enabling timely intervention and reducing the likelihood of catastrophic failures, this dual-strategy solution contributes to enhanced system reliability, improved asset management, and the long-term sustainability of modern power electronic infrastructures. Future work will focus on expanding the predictive framework using machine learning algorithms and integrating cloud-based platforms for large-scale deployment and remote diagnostics.

#### References

1. Rakhmonov I.U., Reymov K.M., Shayumova Z.M. The role information in power management tasks//E3S Web Conf. Volume 139, 2019. Rudenko International Conference “Methodological problems in reliability study of large energy systems” (RSES 2019) 01080. 1-3 p. <https://doi.org/10.1051/e3sconf/201913901080>.
2. Кузнецов, С. В. Воздействие термических и электрических нагрузок на изоляционные материалы / С. В. Кузнецов // Электротехнические комплексы и системы. – 2020. – № 4. – С. 45–52.
3. Лапшин, С. В. Анализ деградации изоляции силового оборудования на основе ускоренных испытаний // Вестник МЭИ. – 2022. – № 2. – С. 88–96.
4. Карпов, Д. И. Беспроводные сенсорные сети в энергосистемах: архитектура и алгоритмы / Д. И. Карпов // Известия вузов. Электроника. – 2021. – № 3. – С. 56–64.
5. Rakhmonov I.U., Nematov L.A., Niyozov N.N., Reymov K.M., Yuldoshev T.M. Power consumption management from the positions of the general system theory // Journal of Physics: Conference Series. ICMSIT-2020. 1515 (2020) 022054 doi:10.1088/1742-6596/1515/2/022054.
6. IEEE Std 1459-2010. Definitions for the Measurement of Electric Power Quantities under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions / IEEE Power & Energy Society. – New York: IEEE, 2010. – 68 p.
7. Gungor, V. C. A Survey on Wireless Sensor Networks for Industrial Applications / V. C. Gungor, G. P. Hancke // IEEE Transactions on Industrial Informatics. – 2009. – Vol. 5, No. 4. – P. 241–249.
8. Liu, J. Reliability Analysis of Insulation Materials in Power Converters Using Accelerated Life Testing / J. Liu, M. Chen, H. Zhou // IEEE Transactions on Dielectrics and Electrical Insulation. – 2021. – Vol. 28, No. 3. – P. 944–952.

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