Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/10/20230189

A study on the use of digital twin in wind generator gears

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Abstract. With the demand for clean energy is increasing, wind power generators are becoming more common. Although the wind power generation industry has broad prospects for development, there are still problems in wind generator maintenance, especially faulty detection and repair. In order to increase the efficiency of maintenance, the digital twin technology can be used. The mathematical model and the fault tree can help to spend less time alarming. In this article, the use of digital twin in the maintenance and faulty detection of wind generators is analyzed. The methods of faulty detection and the model of fault tree in the maintenance of the wind generator are summarized. In addition, a faulty detection method is proposed through YOLOv5. This method can detect the fault without contacting the gears. The database of faulty detection can be optimized as well. This article may offer a reference for digital twin and fault detection in wind generators.

Keywords: digital twin, wind generator, YOLOv5, faulty detection.

1. Introduction

Wind power generation is an important way for China to solve energy problems and achieve low-carbon energy conservation. With the proposal of dual carbon policy of China in 2021, the new energy power generation industry has broad prospects for development. However, there are still problems in wind generator maintenance. The maintenance steps for conventional wind generators include early warning and judgment, exploration preparation, manual climbing for maintenance, crane disassembly, and final installation. The detection time required accounts for 70% to 90% of the total repair time, while the actual repairing time only accounts for 10% to 30%[1]. Therefore, it is valuable to improve the efficiency of alarming.

For alarming issue, early warning systems in wind power and maintenance optimization devices are designed. Huang proposes a research idea and framework for wind generator operation and maintenance decision-making [2]. Meng conducts research on the structure of common water-cooled wind power gearboxes and analyzed the change rules of key parameters in the gearboxes and established a diagnostic model [3]. Peng proposes a gearbox oil temperature early warning method based on Maximal Information Coefficient (MIC) for the gearbox fault early warning in the wind generator [4]. Zhen uses the dynamic time warping (DTW) algorithm to select wind generators with similar operating conditions and improved the prediction performance of the wind generator gear set model [5].

To make alarm more efficient, digital twinning and early warning control systems can be used to improve the efficiency of wind generator gear maintenance and reduce the risk of the work. Ren uses

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digital twinning technology to enhance the sample of bearing faults based on the data of wind generators and realized intelligent diagnosis of bearing fault modes and causes [6]. Yang designs a method for wind generator data collection and governance based on cloud edge collaboration [7]. Hu verifies the efficient real-time approximation ability of the digital twinning simulation system [8].

In this paper, the existing problems in the maintenance are analyzed. The mathematical model and application of digital twins for wind generator gear sets are summarized. For advanced technology and higher efficiency in maintenance of wind generator, the application on gear sets and the influence of digital twinning on maintenance issues have been analyzed. The human-computer interaction for digital twins has been concluded. In addition, a target-detecting method for wind generator gear sets is proposed. The method can detect the fault without contacting the gears. The suggestion for optimization in the maintenance of wind turbines has been made. This article may offer a reference for digital twin and fault detection in wind generators.

2. Shortcomings of wind generators

2.1. Fault positions in wind generator gear sets

2.1.1. Gear fault. The reasons for the gear fault can be seen as follows:

(1) Sudden increase of stress. When the generator is working at a high rotational speed, a sudden shutting down could cause the vibration of the transmission chain. The meshing clearance of the gear becomes small, and the stress increases instantaneously, which can cause the root fracture.

(2) Poor material and poor quality of heat treatment. The long-term operation with fatigue can make the gears break with the material and the heat treatment.

(3) Poor assembly process and poor coaxiality deviation. They cause the uneven meshing clearance of the gears. The stress on the surfaces of teeth is too high to cause the root fracture. The worn gearbox and the looseness of the fixed bolts on the gearbox could cause the vibration and the coaxiality deviation.

(4) Low oil level, poor oil quality and impurities make the gears unable to form the oil film well. The poor lubrication causes tooth breakage.

2.1.2. Bearing fault. When the performance of bearings fails to meet the requirements for use, the bearings may break. The main causes of bearing failure can be seen in the following situations:

(1) Poor bearing manufacturing process. The unqualified bearing results in uneven stress distribution, and the uneven stress reduces the life of bearings.

(2) Poor lubrication and sealing. Impurities may enter the interior of the bearing, causing abnormal friction and wear.

(3) Overload operation. The overload may cause excessive bearing deformation, and the deformation leads to premature failure.

2.1.3. Gearbox fault. The main parts of the cracking are the rings of gears. The following cases can lead to the cracking:

(1) The material of the gearbox is unqualified.

(2) Gear box installation process doesn’t meet the requirements.

(3) The planetary gears in the gearbox are broken, causing the rings to crack.

2.1.4. Shaft fault. The shaft fault could be caused by the stress. The shaft fault includes shaft bending, shaft breaking, shaft wear. The stresses include tensile and compression stresses, the torsional stress, the bending stress, the shearing stress and the thermal stress. Some shaft faults can be caused by the bearing fault. The worn bearings can generate and increase the stress on the shafts.

2.1.5. Fastener fault. If the rotating speed of the shaft is too high, the generator could generate much electricity and heat. That can give a rise in the temperature. The heat can generate the thermal stress in gear sets and cause the shaft fault.

2.1.6. Seal fault. A poor sealing condition can cause the leakage of oil, and that can cause low oil level and increase friction between gears and bearings. The fault can cause shaft fault and bearing fault. The assembly and material of the bearings and gearbox can cause seal fault.

2.2. Gear sets maintaining problems

2.2.1. Faulty alarming problems.

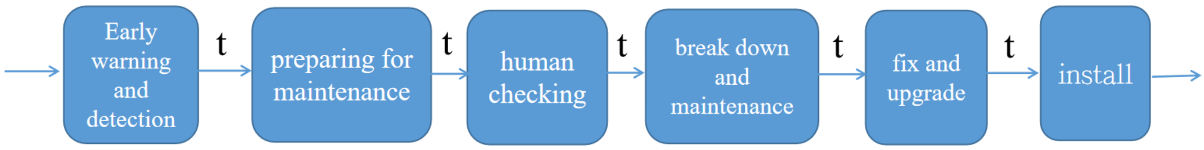

Figure 1. Structure of maintenance steps and processes.

As shown in figure 1, the steps of maintaining wind generators can be concluded into a control system. The present study confirms the findings about the length of maintaining. The alarm takes about 70%~90% of the length while the others take up 10%~30%. The capacity of the single units in wind generators is becoming larger, and the structure of the units is more complex. Therefore, The probability of failures will also increase. If the warning decision-making time is too long, it can delay the optimal operation and maintenance. The delay can also decrease the production and increase the cost. During the maintenance of wind generators, secondary damage may occur due to the harsh working conditions.

2.2.2. Imperfect database for working condition. There are different types of lubricating oil for the gear sets, and some of their impacts are not considered in the database. The lack of data leads to the failure of early warning after replacing the old lubricating oil with new types. Due to the different materials and structures of gear sets, the impact of lubricating oil on them varies.

At the same time, the recorded data for the mixed effects of multiple wind directions and wind speeds is not complete. Due to the working conditions, the wind speeds and the directions vary. In some cases, wind generators can only be shut down without making reasonable use of the energy.

Since most of the wind generators locate in remote districts, the communication faces significant challenges. The lack of data transmission capacity also increases the difficulty of maintenance. Therefore, wind generators need digital twin platform to deal with the problems.

2.2.3. Climbing height for maintenance. The common gear sets of wind generators in China have a height of between 120 and 140 meters, and the small independent height of wind generators are also close to 100 meters. The maximum height of the wind generator has exceeded 160 meters. Some wind power plants use automatic elevators to transport technicians for maintenance, while operation and maintenance for offshore wind generators require helicopters to carry workers for manual repair. The replacement of the wind generator gear sets requires a lifting machine for loading and unloading. It also needs staff to reach the top of the tower for inspection and maintenance. The technicians even have to climb up to the top with bare hands for replacement. And the disassembly of the gear sets after failure is relatively difficult. The different specifications and sizes of wind generators also increase the difficulty of maintenance.

3. Wind generator digital twin platform

3.1. Digital Twin Platform theory

The gear sets in the wind generator serve as a significant part transforming the energy from the generator blade into the generator. Up to now the most of gear sets in wind generators in China are planetary gears, and the majority of their efficiency have reached 95%. The gear box can protect the gear sets from counterforce and enable gears to work efficiently, without which the dust could cause abrasion and noise, and several chemical substances can corrode the gear, decreasing its efficiency.

In addition, the analysis of stress on gears plays an important role in their efficiency. Since the working conditions of generators vary through the weather and temperature, the wind overloads the generators and gears easily. The maintenance of wind generators and their gears needs lots of manual detection, and it's labor-intensive and time-consuming.

The digital twin platform used for alarming can send the parameters to the computer through sensors and mathematical model, and the platform can make working condition of gears visual and achieve virtual mapping, mirroring the malfunction and errors.

3.2. Fault tree for faulty detection

Dividing the faults in the gear box and sending the feedback to the top can deal with a variety of malfunction, and they can create a logic diagram called fault tree. The diagram reflects the elements which cause faults in the gear box. The elements include hardware, software, environment, and human factors. The fault tree can estimate the warning level.

According to the fault tree, the top of the logic diagram is the system fault, which can be divided into gear fault, shaft fault, bearing fault, box fault, fastener fault, seal fault and so on. The damage of parts or improper operation is taken as the basic event. As fault of any component of the gear box will cause a system fault, the main logical relationship between the fault is 'or'. The logic diagram and the structure of fault tree are shown in figure 2 and figure 3.

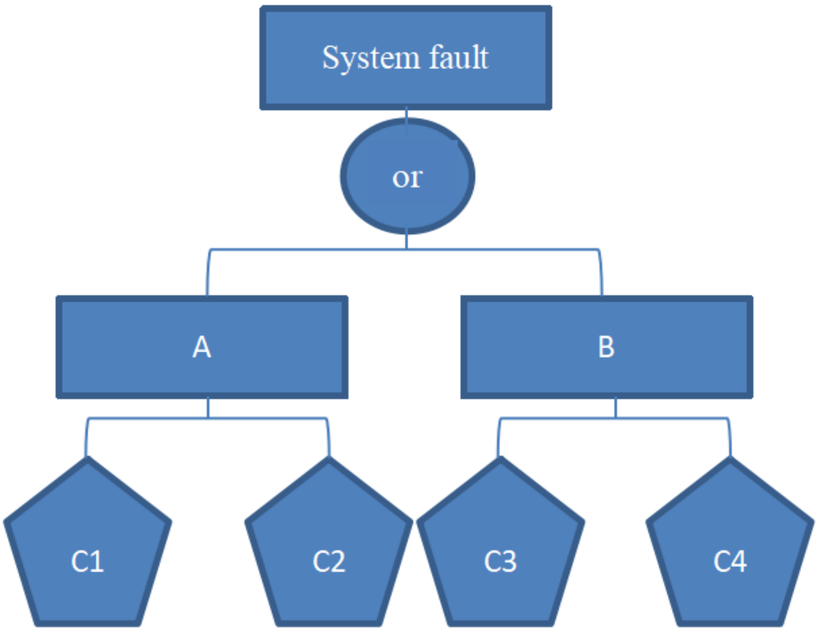

Figure 2. Logic diagram of fault tree.

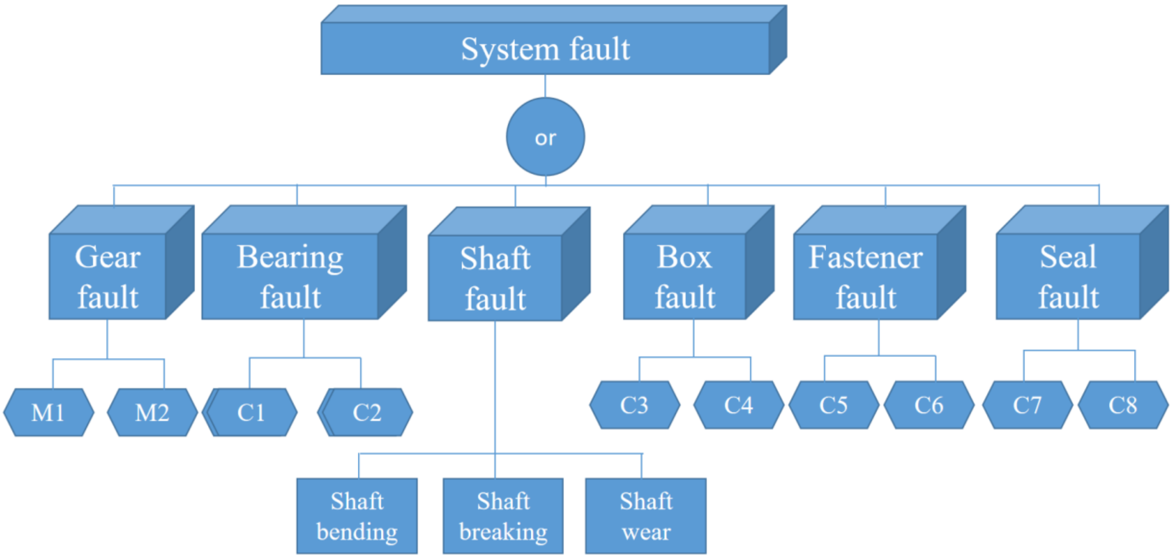

Figure 3. Structure of the fault tree in gear sets.

3.3. Man-Machine conversation

The man-machine interaction and visual perception can be achieved through the sensors and the establishment of expert system.

Digital twin system in the wind generator uses multiple visualization technology, comparing the working conditions at real time. The main interface of the digital twin can display the real-time operation posture of the wind generator, as well as the digital twin wind generator built by the 3D engine, which can visually display the dynamic effects of yaw and pitch. The right side of the main interface displays a set of operational parameters related to the crew attitude. At the same time, it can display environmental information (temperature, wind speed, wind force, wind direction, etc.), key production parameters (wind wheel speed, generator speed, generator torque, generator power, etc.), and dynamic load parameters (shear force in the front and rear of the tower base, stress in the front and rear of the blade root) in a rich and intuitive form. The key parameter graph overlays the actual operating parameters of the wind generator and the simulation parameters of the digital twin model, and it can compare virtualization and reality, so that the manager can monitor the status of the wind generator at all times.

With a database for the wind generator and its gear sets, digital twin can also display the temperature of the tower and engine room for monitoring and early warning. The digital twin platform can provide 3D rendering technology. Users can use the zoom on the web to view the status of different parts of the wind generator. Different parts in the cabin will display different colors based on actual operating temperature. At the same time, the level of cabin and type can be viewed through the alert interface.

4. Recent advance in faulty detection

4.1. Image detection theoretical basis

With the development of artificial intelligence, a large number of facts have shown that deep learning and neural networks can reduce human labor intensity and improve detection efficiency. Using the machine vision to assist in manually detecting wear cracks in the gear set can reduce the risk of maintenance work to a certain degree, and it can help early warning decision-making through the Internet of Things (IOT) by remote control. However, some detection processes are still complex, and some systems ignore the fault information.

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Thus, methods for improvement are proposed. Liu proposed a fault early warning method for wind generator condition monitoring based on deep convolutional automatic encoder(DCAE)[9]. Chen simplifies the fault feature extraction process and improves the accuracy of fault diagnosis.

4.2. YOLOv5 for faulty detection

YOLOv5 is a single-stage target detection algorithm, and openCV is a common program module for YOLOv5 target detection[10]. The YOLOv5 network structure and the specific structure of each module are shown in the figure 4. The YOLOv5 network can be divided into two parts. The front and rear backbones and the head. 'C3b1/2_n' represents the C3 module. 'b1/2' indicates that the BottleNeck1 or BottleNeck2 module is used in the C3 module, and 'n' indicates the number the BottleNeck module in the C3 module. For example, 'C3b1_3' represents a C3 module in which the BottleNeck1 module is used, and there are 3 BottleNeck1 modules. The YOLOv5 model includes YOLOv5n, YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x. They use the depth_ Multiple and width_Multiple to control the depth of the model and the number of output channels at each layer.

Figure 4 demonstrates the establishment of a data set. 50 samples of different fault types of wind generator gear sets are collected, and the data is labeled. The XML file can be converted into YOLOv5 format. The prepared data can be numbered and create sub serial numbers. Then, openCV downloads the priori frame through the file, and a file that stores weights and coordinates is configured. Figure 5 shows that typical sample data sets can be obtained. The fault locations of the gear set are shown in the red box.

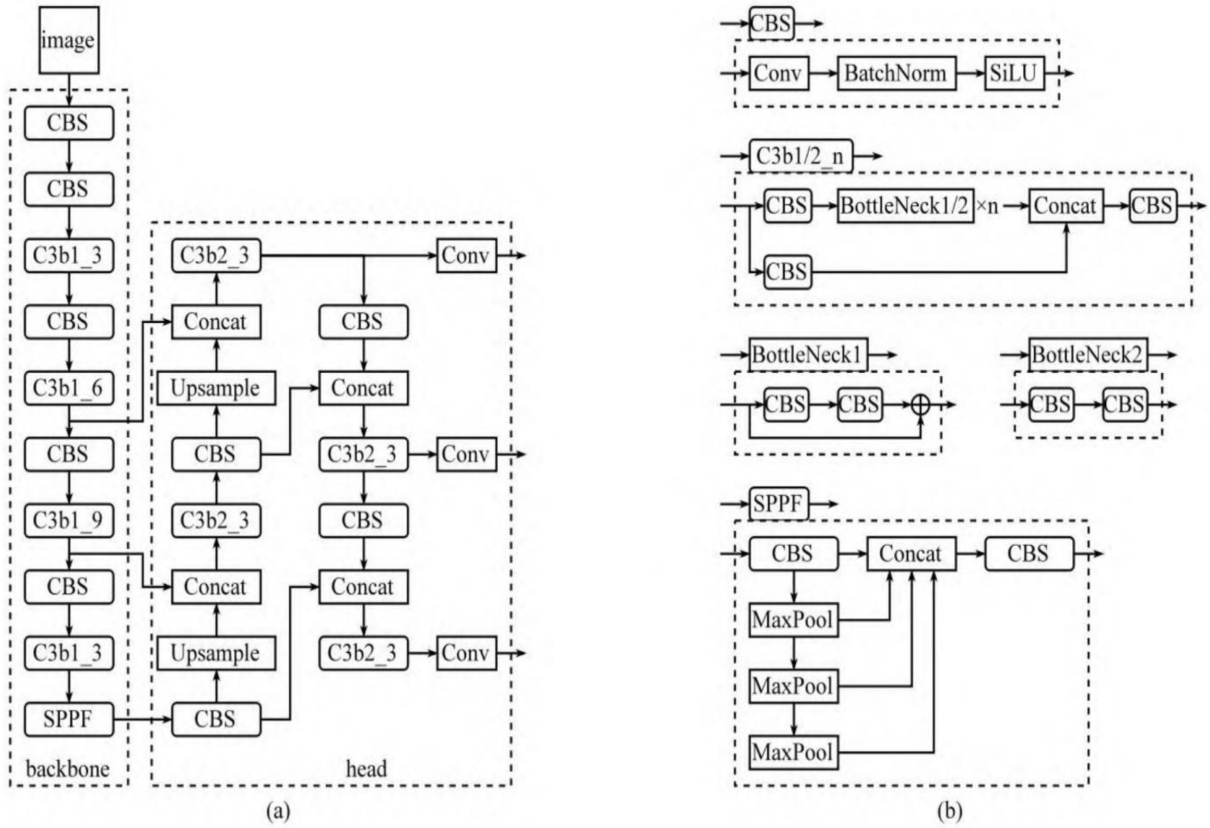

Figure 4. Structure of YOLOv5.

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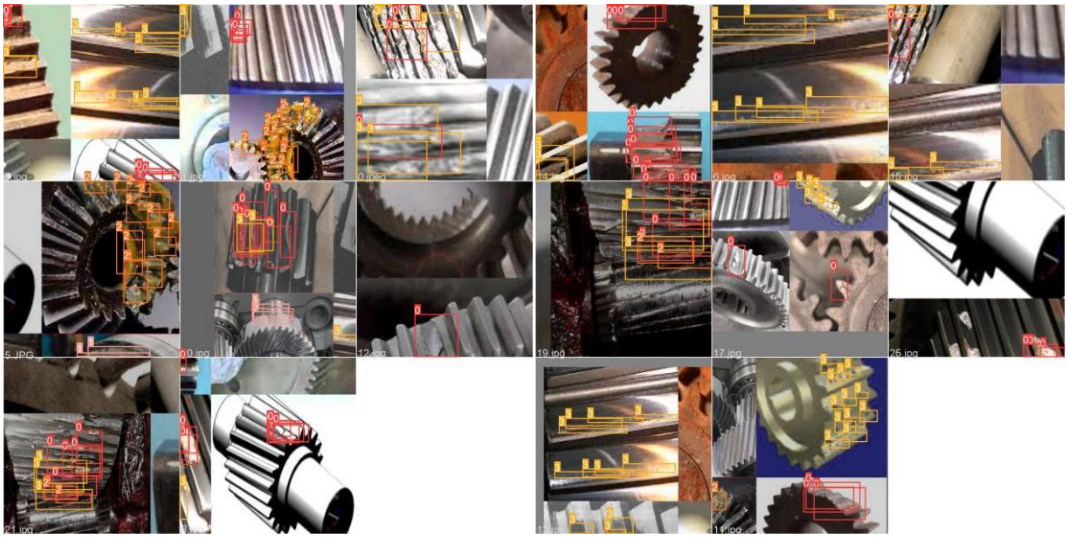

Figure 5. Data set of gear fault.

It can be seen that the fault location of the gear set can be visualized by establishing a YOLOv5 model, but some smaller gear faults have not been identified yet, while the model can achieve a detection rate of 90% for gear set wear faults. As shown in figure 5, the data set can analyse the gear faults and visualize them automatically without manual detection.

Target detection can be upgraded to a non-invasive fault detection method based on convolutional networks. The total current and voltage signals of the motor and other equipment can be measured and collected while they are working together. A large number of tagged samples represent different faults. A new one-dimensional convolutional neural network structure and residual back-propagation algorithm can enable the network to extract features automatically through multiple iterations. The system makes it suitable for non-invasive data collection without the need to manually extract faults, and the connection between the total power signal and the motor operation is established, and it allows the system to detect and judge the motor faults without contacting. The structure of non-invasive fault detection model is shown in figure 6.

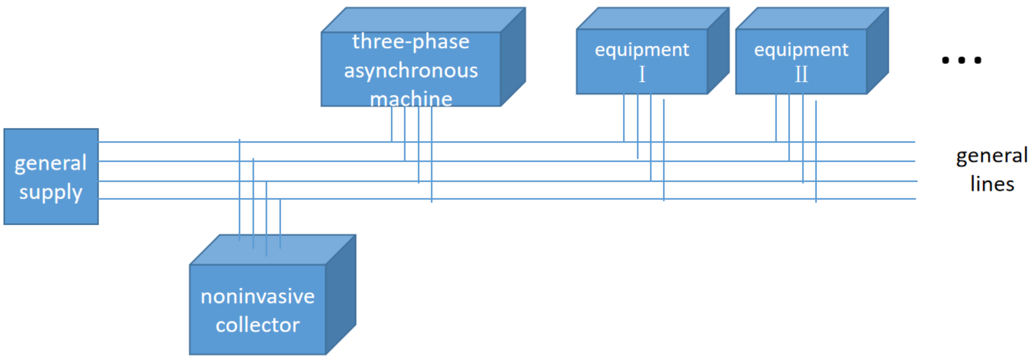

Figure 6. Structure of non-invasive fault detection model.

From the above, it can be seen that machine vision and neural network have three advantages in the digital twin of wind generator gear sets:

(1) Perception and human-computer interaction can be achieved through non-contact and remote control.

(2) The malfunctions of generator and gear sets are sent to the processing layer through collection and transmission, facilitating information visualization.

(3) Machine vision target detection doesn't generate fatigue and can improve the detection efficiency compared to human exploration.

The limitations of the present studies naturally include:

(1) For new and special situations, machine vision target detection can't update itself due to a lack of similar features in previous databases, and it fails to send the message in time.

(2) For gears operating at high speeds, the non-contact detection cannot meet the operational detection requirements, since image transmission speed is unable to meet image clarity.

4.3. Database optimization for faulty detection

A database can be established for setting boundary condition parameters such as oil and structural damping. Using different parameters under different ambient temperatures and rotation rates can make the simulation conditions closer to real operating conditions. Figure 7 shows the structure of the database. 'n' represents the rotational speed of the gears, and 'T' represents the temperature of working condition.

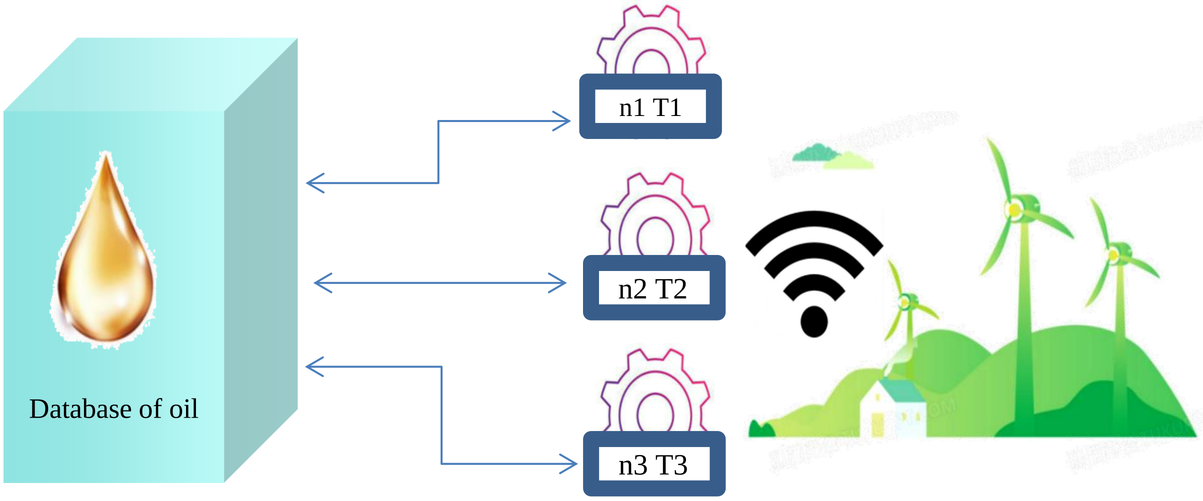

Figure 7. Structure of the database.

5. Conclusion

The faults of wind generator include gear fault, shaft fault, bearing fault, resulting in difficulties for detection and repair. The digital twin platform and image detection technology can be used to solve the problems.

The digital twin platform reduces the labor intensity of manual inspection and maintenance. It also reduces the cost and improves maintenance efficiency. The remote control, machine vision, and other new technologies can be used in the operation and maintenance for gear sets of wind generators. The application of digital twins in the logical tree model of wind generator gear sets is summarized. And problems in the maintenance efficiency of the gear sets are discovered. The implementation of human-computer interaction for digital twins in wind generator gear sets has been summarized. In order to improve the efficiency of detection, a method for detecting wind generator gear set targets based on YOLOv5 image detection is proposed.

With the continuous development of wind power technology, operation and maintenance for wind generators will become easier. The warning process will become earlier and more accurate, making contribution to establish IOT for wind power. Through the machine learning and connection between the database and the generator, the operation and maintenance of wind generators gear sets can be more comprehensive, and the connection can improve the utilization of wind power.

References

[1] YANG Z, WANG B, DONG X, and LIU H 2011 Systems Engineering Procedia 4 189-195

[2] HUANG L, FU Y, REN H, WEI S,and HUANG Y 2020 Proceedings of the CSEE 40(21) 7065-7078
[3] MENG K, TENG W, PENG D, XIANG L, and LIU Y, 2023 China Mechanical Engineering 1-11
[4] PENG L, LIU X 2022 Computer and Information Technology 30(3) 49-52
[5] ZHEN C, ZHANG Z, GUO D, and LIU Z 2023 J.Zhengzhou Univ.(Nat. Sci. Ed.) 55(2) 88-94
[6] REN W, ZHANG W, LI M, XU X, and LIU H 2022 Journal of Projectiles Rockets Missiles and Guidance 42(3) 97-104
[7] YANG W, FAN X, SUN R, SUN Y, and DING R 2022 Journal of Projectiles Rockets Missiles and Guidance 1-8
[8] Hu Y, Wang W, Fang F, Song Z, Xu Y, and Liu J 2023 Journal of System Simulation 1-8
[9] Liu Q, Xu S, and Yu M 2022 Science Technology and Engineering 22(6) 2326-2333
[10] Fang F, Yao G, and Hu Y 2022 Sci Sin Tech 52(10) 1582–1594