SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Wind Rose Analysis of Temperature Variation with Sensor Implantation Technique for Wind Turbine

Anant Sidhappa Kurhade[1,*], Pushparaj Warke[1], Kamalkishor Maniyar[1], Parimal Sharad Bhambare[2], Shital Yashwant Waware[1], Sushil Deshpande[1], Sunilkumar Harsur[1], Murlidhar Ingle[1], Pankaj Kolhe[1], Prashant Ashok Patil[1], Pallavi Abhinandan Jadhav[1], Prajakta Pawar[1]

[1] Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology Pimpri, Pune, Maharashtra 411018, India
[2] Department of Mechanical and Industrial Engg, College of Engineering, National University of Science and Technology, Muscat, Oman

ARTICLE INFO

Article history:
Received 15 May 2024
Received in revised form 5 September 2024
Accepted 17 September 2024
Available online 10 October 2024

Keywords:
Wind turbine; wind rose analysis; heat transfer; sensors

ABSTRACT

This study focuses on analysing the impact of seasonal variations in heat on different parts of a "wind energy system," serving as a representative mechanical system. The proposed methodology utilizes wind rose analysis, offering a straightforward means to assess heat transfer effects, applicable to any mechanical system comprising numerous small heat-dissipating components. Furthermore, this work elucidates the correlation between mechanical component performance and heat dissipation impact, providing breakdown alerts for various wind turbine components. Additionally, it analyses the influence of mechanical part temperatures on energy generation, highlighting how high temperatures can indicate component deterioration, such as bearing damage. Notably, the study focuses on wind speeds ranging from 10 to 15 m/s, a typical operational range for wind turbines. By employing wind rose charts and real-time readings, the graded heat dissipating potential of mechanical parts under various wind velocities and weather conditions is determined. Moreover, the study emphasizes the significance of heat transfer analysis in optimizing wind turbine performance, demonstrating how temperature differentials between mechanical components and the environment, along with increased surface area, affect heat transfer. The proposed analysis underscores the importance of considering heat's impact on each mechanical component in tandem with seasonal environmental temperature fluctuations. The wind rose methodology, integrated with sensor implantation, emerges as a cost-effective tool for studying -level heat variances in mechanical systems, enabling the development of heat profiles for future turbine designs and computational fluid dynamics (CFD) analyses. As heat transfer coefficient increases the wind turbine performance decrease. The heat transfer coefficient decreases 14.28% from rainy to winter season and 42.85% from winter to summer season. The wind rose analysis provides valuable insights into wind patterns and characteristics at a specific location, which can inform decision-making in various fields such as energy, construction, environmental management, and safety planning. As the turbine temperature increases the wind velocity decreases. Here it decreases 28 % from rainy to winter season.

---

[*] *Corresponding author.*
E-mail address: a.kurhade@gmail.com

https://doi.org/10.37934/arfmts.122.1.118

1. Introduction

Nowadays, the importance of the sustainable energy, is considerably enhanced Carotenuto *et al.,* [1]. The various pressure transducers and thermocouples were used to measure the pressure and temperature evolution respectively. Cao *et al.,* [2] presents the temperature evolution during the gas phase and dense phase. Existing research investigated the radiative three-dimensional weaving convection flow of surface Nilsson [3]. A number of analytical and experimental works investigating the performance of thermal systems are available in the literature. In existing analysis developed a numerical model able to replicate the mechanical and thermal behavior to analyze the impact of thermal enforcement on the system behavior.

As per Barry Manz of Mouser, industrial IoT in action can be used in wind turbines with all the necessary ingredients from sensors to the networks that connect them though Ethernet. A wind farm with IIoT network gives the benefits of historical operating data such as wind speed, power, yaw angles, gearbox temperature, various elements contributing in heat transfer and other metrics to analyze trends. From this data, one can develop a model that can guess which and what components to inspect and when. All the information, status alerts and other results can be viewed and actions taken from a smart phone, tablet, or computer. This is definitely a new development path for mechanical engineering, energy sector, electronics sector with different scopes of work.

According to Fino *et al.,* [4], the heat transfer can be impacted by variation in moisture content developed by weather conditions. For comparison purpose, winter and summer environmental conditions for both dry and wet weather were assumed. The results show that in rainy period the thermal behavior of the wall is only affected, until the first few hours when the expanded cork board starts to dry. The temperatures of water film surface, the bottom of a cylindrical plastic cuvette and a graphite substrate are measured [5]. The experimental data shows the study of rapid evaporation of a liquid at internal and external interfaces of water drops containing solid opaque particles with a further explosive fragmentation of water film. This mechanism relies on heating of the particle surface above the boiling point of water. A dynamic heat transfer model is developed via steady heat transfer experiment and theoretical analysis for the north wall implanted with heat pipes in summer months [6]. Results show that the inner temperature field of the north WIHP presents obvious upper and lower partitions in summer. The delay time of the ordinary wall is more than the WIHP by 1.38 h. The average temperature of the north WIHP is 2°C lower than that of an ordinary wall, which represents an effective improvement to the indoor thermal environment. In this paper, a new method is developed which meet the demand for humidifying the indoor air in winter by using desiccant coated heat exchanger (DCHE) as a heating and humidifying unit during the regeneration process [7].

Gai *et al.,* [8] shows the heat transfer coefficient associated with the hollow-shaft rotor cooling of a traction motor. Lehmann *et al.,* [9] describeD the required models for temperature estimation before discussing the influence of the machine environment on its performances. The RNG k-ε turbulence closure, discrete ordinates (DO) non-grey radiation model and solar ray-tracing algorithm were employed [10]. Effects of mixed convection, thermal radiation and heat generation/absorption are discussed [11]. Newtonian conditions for heat and mass transfer are considered. Improvement in thermal performance of PHPs will lead to higher heat transfer capacity and enhancement in the efficiency of systems which PHPs are applied [12]. The thermal conductivity and viscidity of the base fluid is increased by adding graphene oxide sheets. With study of various heat elements and heat transfer coefficients evaluated within existing research, proposed work is designed to evaluate applied heat transfer. The existing research is mostly based on numerical and CFD analysis. Hence, to provide real time analysis and solution, proposed work methodology is designed with implantation of various temperature sensors. Results are further tested with wind-rose analysis which discussed in further sections. Mourad *et al.,* [13] sheds lights on several lifetime and failure prediction models and outlines recent trends in the additive manufacturing of turbine blades, e.g., core and microstructural grading. Alami *et al.,* [14] discussed 3D printing in wind turbine production on Sustainable Development Goals (SDGs) was primarily evident in three other goals: SDGs 8, 12, and 13, representing 8%, 8%, and 9% respectively. Particularly noteworthy was the impact on SDG 13, as it led to a reduction of approximately 25% in CO_2 emissions compared to conventional manufacturing methods. However, the contribution to the remaining SDGs was minimal, with none exceeding 3%. Poddaeva and Fedosova [15] discussed a comprehensive wind rose detailing extreme wind speeds are currently under development. This approach is being applied in two distinct Russian regions: Moscow, where extreme wind speeds are infrequent, and the Far East of Russia, where they are more common. Recommendations for construction stages in these regions are being provided based on this analysis. Arteaga-López and Angeles-Camacho [16] showed that how that VCD improved the micrositing of wind turbines, as compared with conventional CFD studies. Kurhade *et al.,* [17-20] studied numerical study of PCM cooling for smart-phone and thermal performance. Patil *et al.,* [21], and Waware *et al.,* [22,23] provide critical reviews on heat transfer and Heat Transfer Enhancement in Tubular Heat Exchangers with Jet Impingement. Rahul Khot *et al.,* [24-28] explain the investigation on Laser Welding Parameters on the Strength of TRIP Steel. Gadekar *et al.,* [29,30], and Gadekar and Kamble [31] explained experimental study on gear EP lubricant mixed with Al_2O_3/SiO_2/ZrO_2 composite additives to design a predictive system. Patil *et al.,* [32] used a water-based Al_2O_3 nanofluid was used in this work to grind materials due to its outstanding convective heat transfer and thermal conductivity qualities. Patil *et al.,* [32] delves into cooling square heat sources, particularly comparing different working fluids. Fluorocarbon liquids are favored for their ability to handle higher heat fluxes due to their high boiling points; liquid jet impingement reduces electronic component temperatures by 80 to 85 degrees Celsius. Poddaeva and Fedosova [33] explain offers a statistic extreme wind speed analyses with Methodology for testing the statistical significance between different wind speeds and directions. Diaz *et al.,* [34] explains for wind farm, considering both wakes and terrain results in errors that cancel each other out, closely matching the measured values. Additionally, increasing the number of simulated direction sectors from 16 to 32 has little impact on the results. Arteaga-López and Angeles-Camacho [16] showed that VCD improved the micrositing of wind turbines, as compared with conventional CFD studies.

Hence, this paper considers the wind energy system as a cluster of mechanical parts for heat transfer/thermal analysis. The new sensor implantation technique (SIT) is developed to record the temperature of each component. Further, these thermal behaviors are analyzed for wind system components (impeller blades, controller, hub, main shaft, gearbox, mechanical brake, generator, cooling system, anemoscope, wind vane, yawing motor and yawing bearing) for 3 climate seasons (winter, summer and rain) with consideration of environmental temperature variations. By means of this, proposed work contributes in identification of component level thermal behavior of system and can be utilized for troubleshooting in case of any failure occurs. So, it becomes easy to find out reason of failure without total system overhauling.

2. Methodology

The aim of proposed research is to identify the impact of heat and change in heat transfer coefficient based on changing ambient temperature on working of wind system with consideration of subsequent mechanical peripherals. Proposed sensor implantation technique; records the component level temperature. Further, with sensor implantation, temperatures are also recorded for winter, summer and rainy seasons. The heat dissipation due to system working and temperature variation due to environmental changes are considered separately. The role of heat transfer in wind system functioning is very crucial but less focused in previous research. Hence, the proposed methodology is systematic approach to study this less focused domain. The specific research methodology is shown in Figure 1.

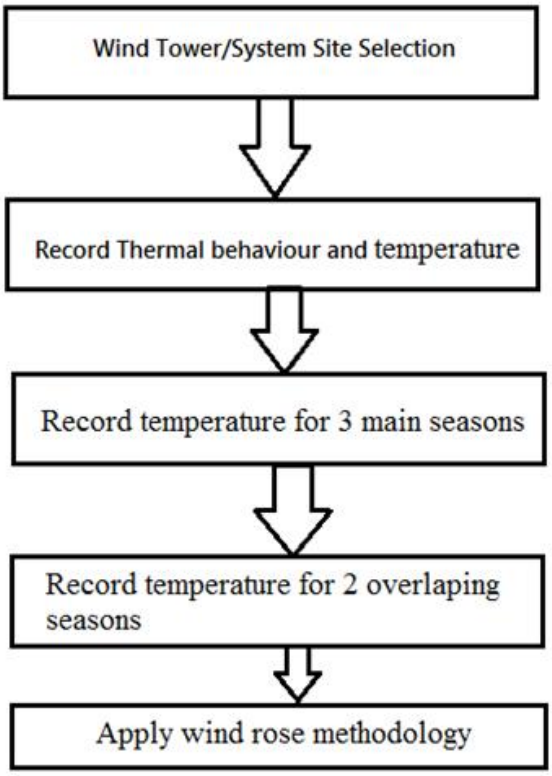

Fig. 1. Steps involved

The values of temperature at different points can be calculated using thermal analysis. Various components of wind system for temperature analysis are represented in Figure 2 below. The components under study are implanted with temperature sensors.

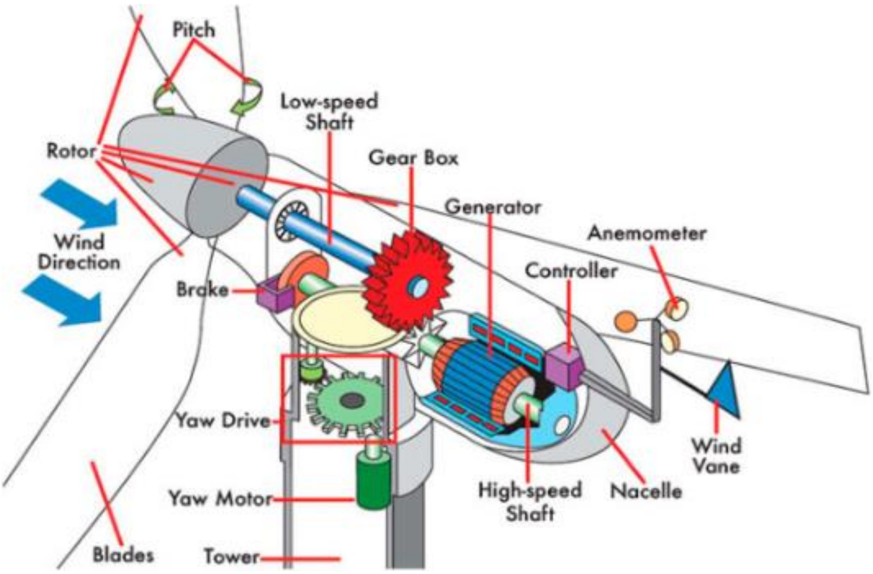

Fig. 2. Wind turbine system

Similarly, offshore wind turbine schematic representation is depicted in Figure 3 below.

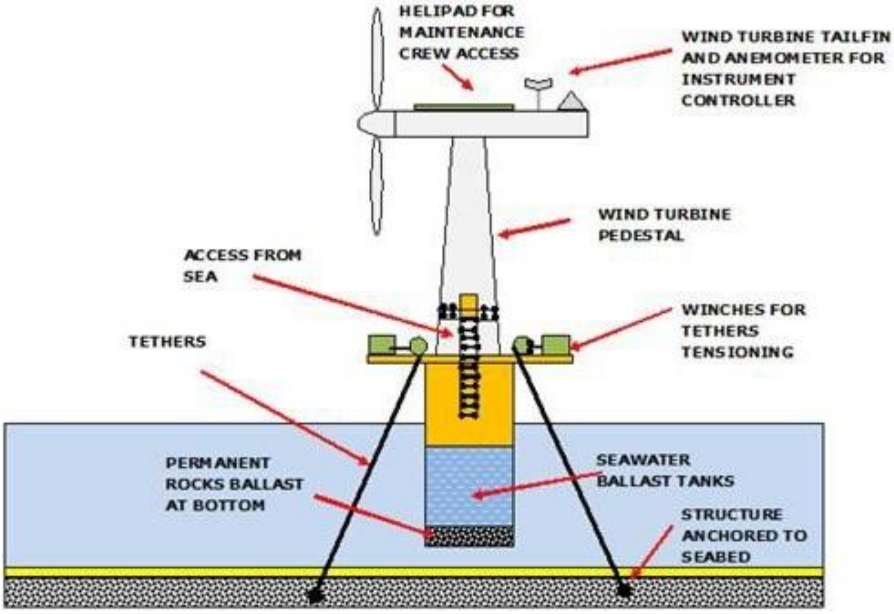

Fig. 3. Offshore wind turbine schematic representation

To execute wind rose analysis, thermal remote sensing is used for blade and blade hub. Thermal remote sensing is based in the infrared portion of the spectrum and measures emitted thermal energy. It is a type of passive remote sensing since it detects naturally emitted radiation. For other parts, (as shown in Table 2) the temperature sensors (NTC-Thermistor) were used for temperature deflection identification. Negative temperature coefficient (NTC) of resistance thermistor, or NTC thermistor for short, reduce or decrease their resistive value as the operating temperature around them increases. NTC temperature thermistor has a negative electrical resistance versus temperature (R/T) relationship. The relatively large negative response of an NTC thermistor means that even small changes in temperature can cause significant changes in its electrical resistance. This makes them ideal for accurate temperature measurement and control. The temperature points of T1 and T2 are calculated in the temperature units of Kelvin and by knowing the B value (material constant) it is possible to produce a table of temperature versus resistance to construct a suitable graph using the following normalized equation

$$\mathrm{B}_{\mathrm{T}_1/\mathrm{T}2} = \frac{\mathrm{T}_2 \times \mathrm{T}_1}{\mathrm{T}_2 - \mathrm{T}_1} \times \ln \frac{\mathrm{R}_1}{\mathrm{R}_2}$$

where, B is material constant, T_1 is the first temperature point in Kelvin, T_2 is the second temperature point in Kelvin, R_1 is the thermistor resistance at temperature T_1 in Ohms, R_2 is the thermistor resistance at temperature T_2 in Ohms.

For illustration purpose (Figure 4) only two points were shown, but in case of actual readings, thermistor change their resistance exponentially with changes in temperature so their characteristic curve is nonlinear, therefore the more temperature points are calculated the more accurate will be the curve and these points can be plotted as shown in Figure 5 to give a more accurate characteristics curve.

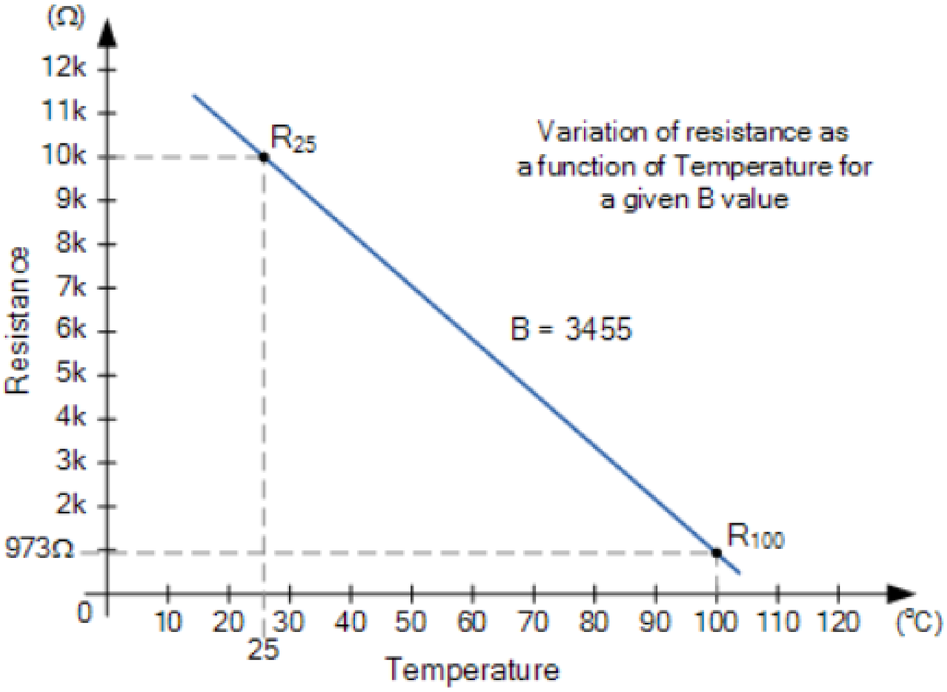

Fig. 4. Characteristics of Thermistor with two point's temperature

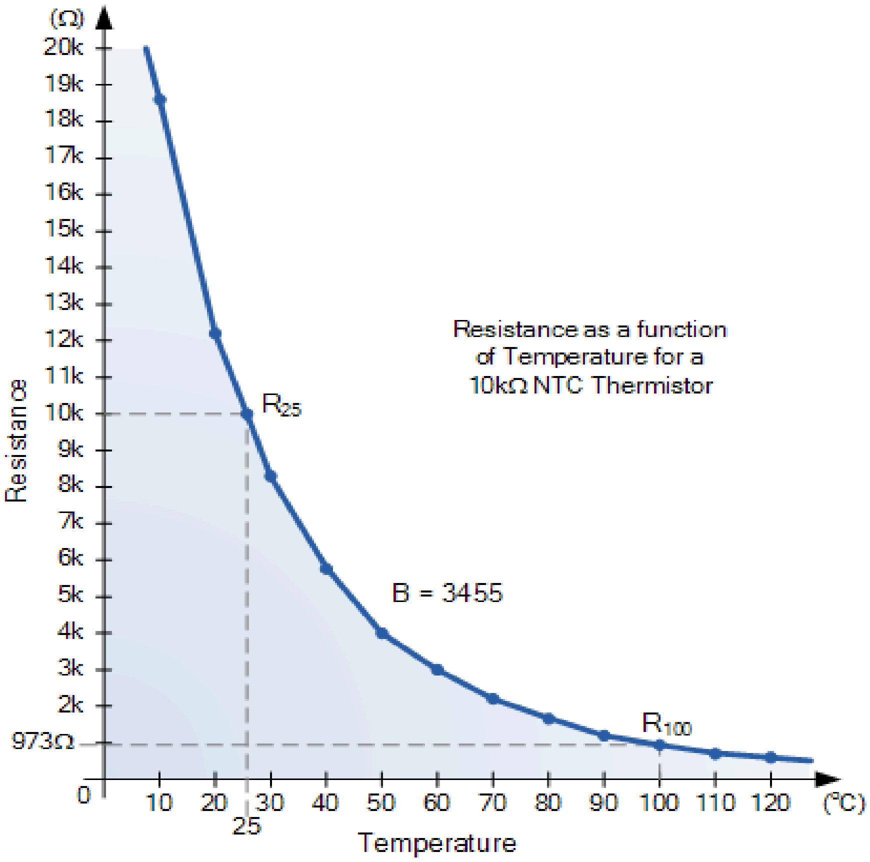

Fig. 5. Characteristics of Thermistor with exponential temperature change

It can be observed from Figure 5 that, it has a negative temperature coefficient (NTC), which is decreases with increasing temperatures. Hence, due to high accuracy, proposed system utilized NTC thermistor as a sensor for further implantation of component level sensors.

2.1 Sensor Implantation

The various components are identified for recording of temperature. Each component is implanted with thermal sensor known as Negative temperature coefficient (NTC) thermistor. Theses implanted sensor readings are recorded for each system components. Further as shown in Figure 6 below, the temperature for environmental deflection is recorded for 3 seasons (Rainy, winter and summer) and 2 overlapping seasons.

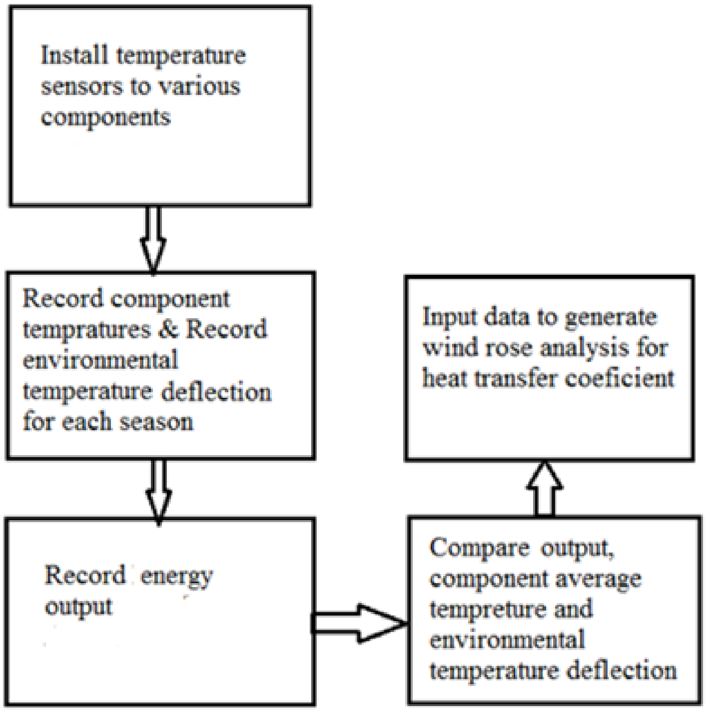

Fig. 6. Sensor Implant Methodology

TE Connectivity's PTF Family Platinum Temperature Sensors are ideal for extreme temperature environments from -200°C to +600°C. A group of resistance temperature detectors (RTD) using a Platinum resistor in thin film technology as the sensing element are combined using sensors. Applications include appliance, industrial, and medical markets. PTF Family Platinum Temperature Sensors are compliant with DIN EN 60751 [16].

As various wind turbine parts shown in Figure 3, each part is implanted with sensors as listed in Table 1 below.

Table 1
Sensors used for onsite testing

Location	Sensor Details
Nacelle, rotor blades, hubs	Harco Semco temperature sensor, Outside Air Temperature Sensors (OAT)
Low speed shaft, gearbox, high speed shaft with its mechanical brake, electrical generator, yaw mechanism	Harco Semco Thermocouple Immersion Probes
Hydraulics system, cooling unit	Harco Semco rigid thermocouple assemblies
Tower, anemometer and wind vane	Harco Semco Environmental System Sensors

2.2 Formulation

A mathematical modeling has been carried out to look for the heat transfer coefficient from the traditional formula model for one structural wind turbine system, and that is essential in the event the local thermal balance reduces. Together with similarity of weather condition (for winter summer and rainy season) completely formulated heat profiles permits to accomplish a mathematical experiment by using individual structural wind turbine unit for finding out the completely developed heat transfer coefficient with no empiricism.

When there is a substantial heat developed, the temperature is generally no more equivalent. The predictions of regional thermal stability have to be removed after we evaluate the entry area of crammed column in which a hot wind moves at the higher velocity. Most of unsteady issues linked to material form, which often enable heat transfer derived from one of stage to another. Once the heat from the bounding surface area changes considerably regarding time period, then when each and every system element have appreciably diverse heat capabilities as well as thermal conductivities, a nearby rate associated with change of heat for just one element is different drastically from that for some other phase. Consequently, we implanted thermal sensors in a single structural wind turbine unit as mentioned in previous section 2.1.

We suggested a mathematical model which will figure out the efficient thermal conductivity of each and every element along with the interfacial heat transfer coefficient of attention. Let's look at a homogeneous heat range (irrespective of season for mathematical modeling) wind flow leading to wind energy system blade movements. As demonstrated in Figure 7, thermal sensors (S1 to S11) are implanted properly.

Consider, an environmental temperature Te, which is less or more than the mean temperature of the components. We consider a single wind turbine tower in which the thermal conductivity is assumed high.

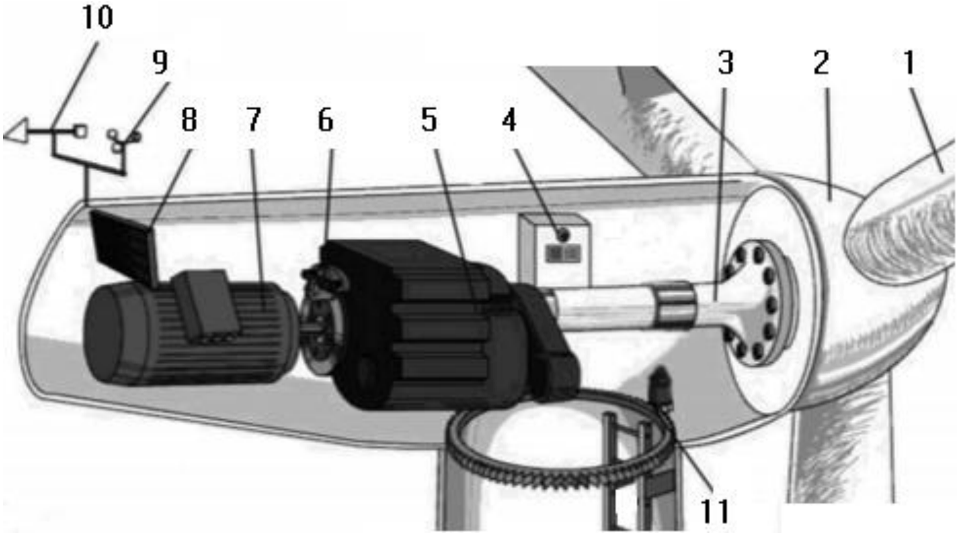

Fig. 7. Schematic representation of single structural unit with sensor implantation; 1, impeller blades (S1); 2, hub (S2); 3, main shaft (S3); 4, controller (S4); 5, gearbox (S5); 6, mechanical brake (S6); 7, generator (S7); 8, cooling system (S8); 9, anemoscope (S9); 10, wind vane (S10); 11, yawing motor and yawing bearing (S11) where ‘S’ shows sensor number

When there is a substantial temperature generation happening in any among the wind system element, the temperature within the two stages is no more similar. Most of unsteady complications can be determined using the implanted thermal sensors, which in turn sense heat transfer derived from one of stage to a different. Once the temperature for the any kind of element surface changes considerably with respect to time, and once every element has substantially distinct heat capabilities along with thermal conductivities, a nearby rate of change of heat for each and every element deviates considerably through that for the various other element.

$$\nabla \cdot \vec{t} = 0$$

$$(\nabla \cdot \vec{t})\vec{t} = -\frac{1}{\rho}\nabla p + v\nabla^2\vec{t},$$
$$\rho_n C_{pn}\nabla.(\vec{t}T) = k_n\nabla^2 T$$

With the routinely entirely formulated phase, the speed syndication in the change of the heat unit must be equivalent compared to that with the wind turbine body, although the heat profile with each component where sensor implanted must be much like that as the wind tower. Thus, the compatibility and seasonal heat transfer mapping is given by means of developed formula:

Consider wind tower with initial temperature,

$$\vec{t} = \vec{0}$$

And component temperature as

$$T = T_e$$

On the periodic season wise boundary:

$$\vec{t}\Big|_{m=0} = \vec{t}\Big|_{m=2T}$$

$$\int_{-T/2}^{T/2} t dy|_{m=0} = \int_{-t/2}^{T/2} t dy|_{m=2T} = T\langle|\vec{t}|\rangle$$

$$(T - T_e)|_{m=2T} = \tau(T - T_e)|_{m=0},$$

Where,

$$\tau \equiv \frac{\int_{-T/2}^{T/2} t(T-T_e)dy|_{m=2T}}{\int_{-T/2}^{T/2} t(T-T_e)dy|_{m=0}} = \frac{(T_B-T_e)|_{m=2T}}{(T_B-T_e)|_{m=0}}$$

TB(m) is the mean temperature of the wind turbine. Computations can be made based on the wind and inline wind turbine velocity$|\langle\vec{t}\rangle|$, the wind turbine temperature is TB and the heat transfer difference is (TB(0)-Te) considered.

For identification of impact of environmental and component temperature on mechanical device performance as well as to avoid micro-level mechanical breakdown due to heat we presented computations for a parametric study.

For such sensor implantation study about micro-level heat transfer or heat generation, we employed the Reynolds number based on temperature of element of wind turbine 'T' as,

$$\mathrm{Re_T} = \left|\langle\vec{\mathrm{t}}\rangle\right|\mathrm{T/v}$$

which is related to the Reynolds number based on temperature similarity of sensors 'S' as

$$\mathrm{Re_S} = \left|\langle\vec{\mathrm{t}}\rangle\right|\mathrm{S/v} = (1-\epsilon)^{1/2}\mathrm{Re}, \text{ as } \varepsilon = 1-(\mathrm{S/T})^2$$

and compared with Reynolds number based on each season temperature of element of wind turbine 'Ts' as,

$$\mathrm{Re_{Ts}} = \left|\langle\vec{\mathrm{t}}\rangle\right|\mathrm{Ts/v}$$

Further, to identify real-time application level impact of heat variations in mechanical system on energy generation, we collected output energy readings from energy administration department. Here the temperatures noted by wind turbine component sensors, environmental temperature and energy outputs are compared. Further, this recorded data is tested by wind rose methodology to generate graphical representation as shown in Figure 8.

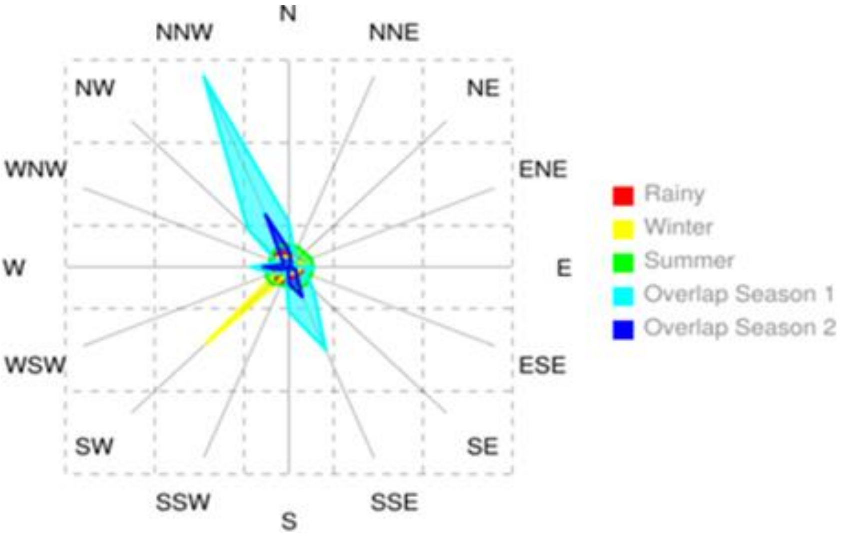

Fig. 8. Wind Rose Analysis

3. Result and Discussions

The wind rose analysis plays a crucial role in various sectors by providing valuable insights into wind patterns and characteristics, thereby supporting informed decision-making, resource optimization, and risk management. It helps in identifying suitable locations for wind farms by providing insights into prevailing wind directions and speeds. In urban planning and architecture, wind rose analysis aids in designing buildings and structures to minimize wind-induced discomfort, optimize natural ventilation, and reduce energy consumption for heating and cooling.

As per research methodology mentioned in section-3, we executed research phase for 1 year. The methodology proved better for identification of seasonal impact with environmental heat impact on mechanical components. The Impact of temperature on wind energy generation is shown with the wind rose analysis in Figure 9 below.

With changing temperature, the power obtained for wind system is computed considering actual readings for period of 1 year. As shown in Figure 1, the ‘Record 2’ recorded during rainy season found low however ‘Record 1’ tested during transit period of summer and rainy season found high as well as uneven. ‘Record 3’ which is tested during transit period of rainy season and winter noted as a substantially stable power output with stable heat impact.

Record 1: During transit period of summer and Rainy season (Overlap Season 1)
Record 2: During Rainy season
Record 3: During transit period of Rainy season and winter
Record 4: During winter season
Record 5: During transit period of winter and throughout summer (Overlap Season 2)

Proposed work helps to understand mechanical component performance correlated with heat dissipation impact and breakdown alert for various components of wind turbine. Also, impact of temperature of any mechanical parts on end energy generation is analyzed. For instance, high temperature may point out destruction of the bearing. A 60°C alert stage could be acceptable within the summer, however in the winter, a bearing having considerable destruction may perhaps merely accomplish at 45°C.

Since the wind turbine normally functions within the situation that the wind velocity is greater than 9 m/s, hence just the situation having a wind velocity which range from 10 to 15 m/s is going to be deemed. Presenting a situation position each and every time by improving velocity of 1 m/s, the wind will likely be together with 6 diverse velocities. The graded heat dissipating potential of the mechanical parts related to different wind velocities along with for 3 diverse weather conditions can be acquired through the wind rose chart and real time readings shown in Table 2.

Table 2
Wind-rose Analysis of climate, wind velocity and heat dissipation of sensor implanted mechanical components

Climate	Wind Velocity (m/s^2)	Turbine temperature (TB)	Environment temperature (Te)	Component Sensed mean temperature (TB(0)-Te)	Output power Q
Summer	10	40.5	38.5	2.0	59.0
	11	40.5	38.9	1.6	59.5
	12	42.7	41.4	1.3	62.5
	13	43.9	41.7	2.2	61.0
	14	43.8	41.7	2.1	61.0
	15	45.0	43.5	1.5	60.0
Winter	10	19.5	17.5	2.0	55.5
	11	18.7	16.3	2.4	55.5
	12	15.8	14.5	1.3	57.5
	13	12.8	11.5	1.3	58.0
	14	9.7	8.0	1.7	58.0
	15	9.5	8.0	1.5	59.0
Rainy	10	23.0	22.5	0.5	55.0
	11	23.0	22.0	1.0	56.5
	12	20.5	20.0	0.5	56.5
	13	21.2	20.5	0.7	59.0
	14	20.5	20.0	0.5	59.0
	15	20.5	20.0	0.5	59.0

Further, based on observed readings, performance optimization is shown in Figure 9 to Figure 14. The mechanical component's heat mapping is recorded using sensor implantation technique. The changing climatic condition, changing wind velocity are compared with heat transfer coefficient which is similar to mathematical proof (i.e. Reynolds's number). Performance of wind turbine and heat transfer coefficient based on different ambient temperatures is shown in Figure 9 below. As heat transfer coefficient increases the wind turbine performance decrease. It decreases 14.28% from rainy to winter season and 42.85% from winter to summer season.

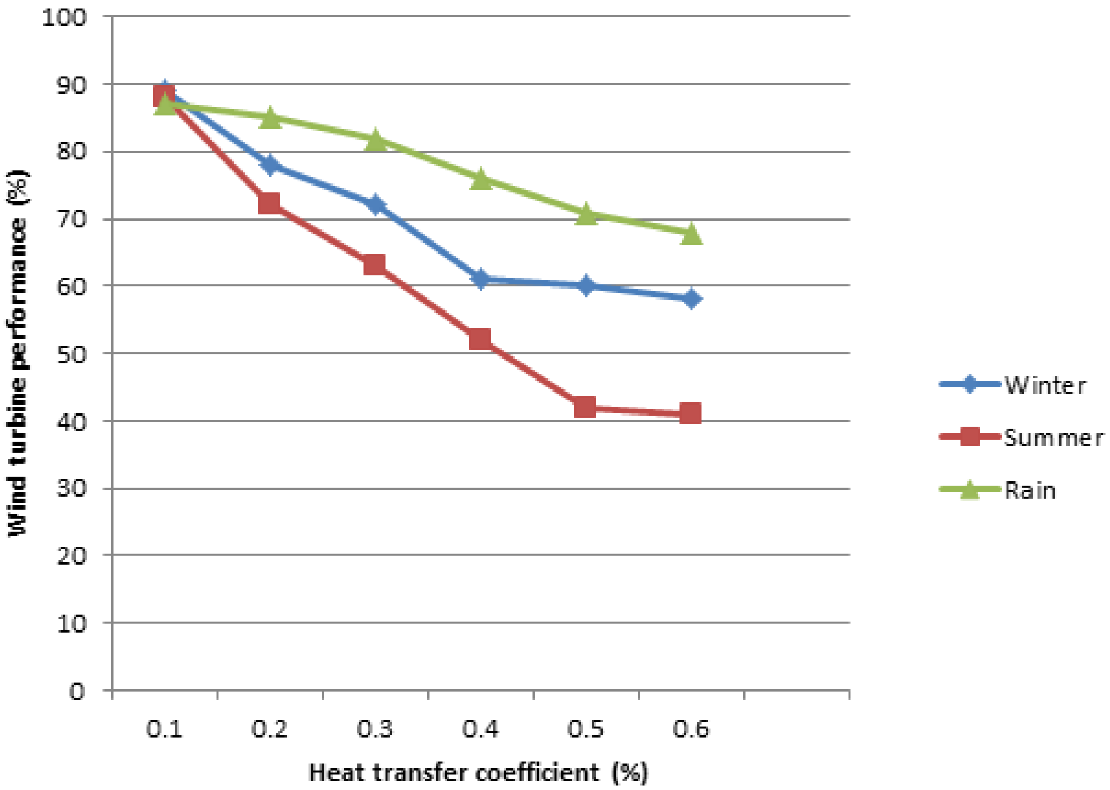

Fig. 9. Performance of wind turbine and heat transfer coefficient based on different ambient temperatures

Performance of wind velocity and wind turbine temperature based on different ambient temperatures is shown in Figure 10 which is the mean temperature graph. As the turbine temperature increases the wind velocity decreases. Here it decreases 28 % from rainy to winter season. The summer climatic condition is critical for mechanical component failure due to high environmental temperature and friction generated heat. But, in case of high wind velocity, environmental temperature impact lower at some extent.

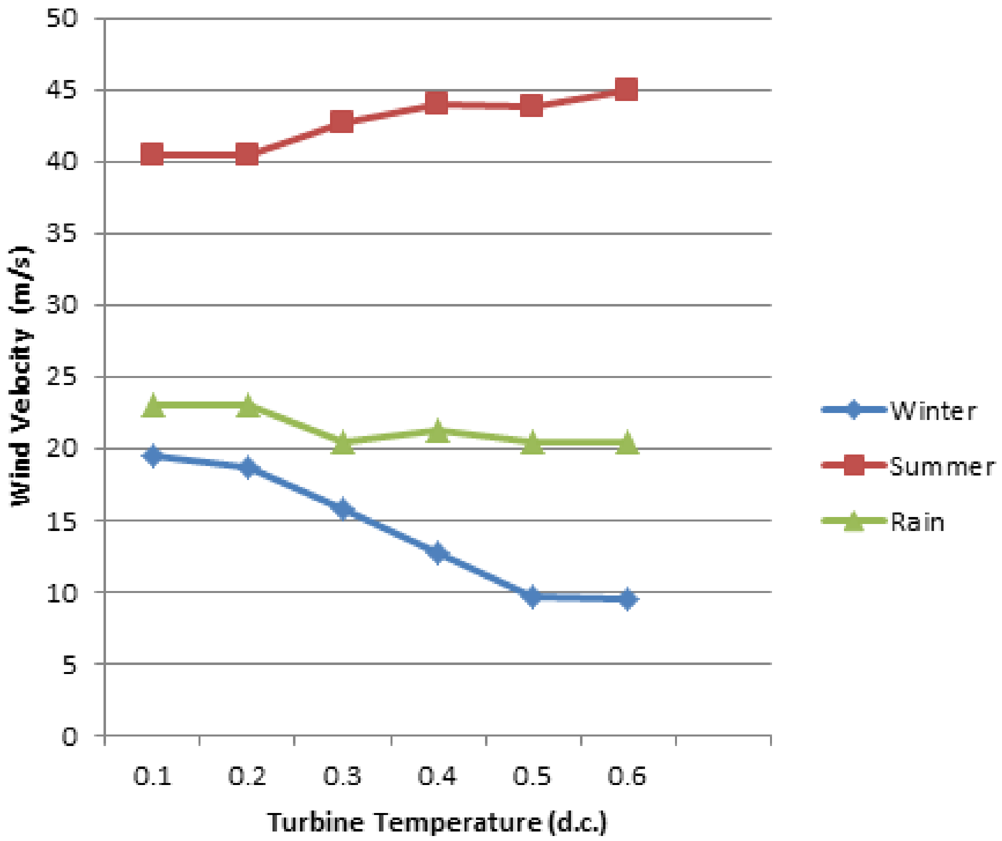

Fig. 10. Performance of wind velocity and turbine temperature based on different ambient temperatures

As the core objective of this work is to identify, heat mapping for mechanical components, Figure 11 shows performance of wind velocity and turbine component mean temperature based on different ambient temperatures. The performance of wind turbines is influenced by ambient temperature variations. While higher ambient temperatures may lead to reduced wind speeds and increased turbine component temperatures, lower ambient temperatures can have the opposite effects. Understanding these relationships is essential for optimizing wind turbine operation, maintenance, and energy production in diverse environmental conditions. The wind velocity decreases with respect to component mean temperature.

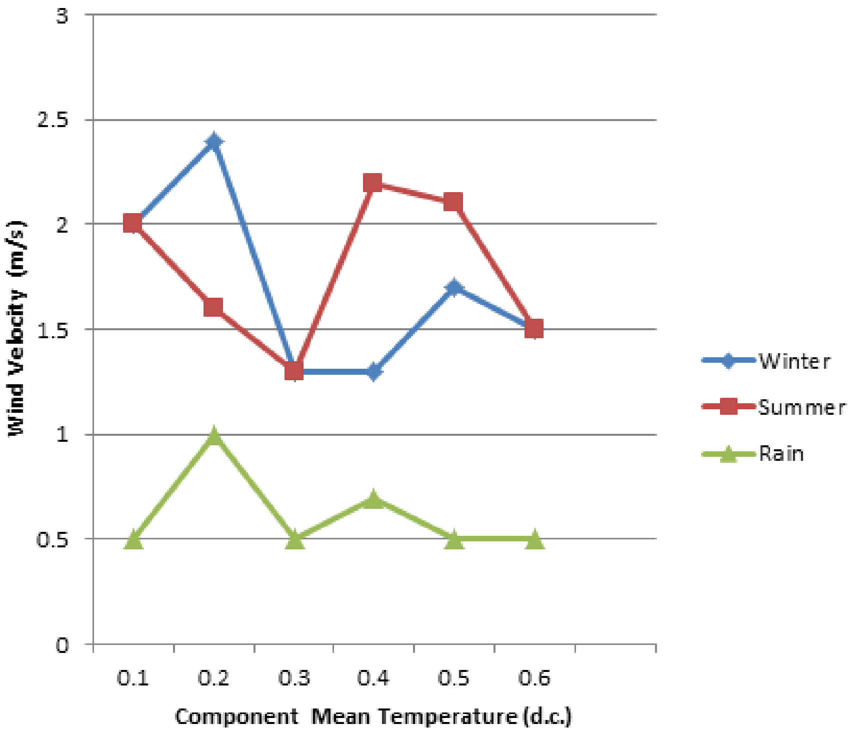

Fig. 11. Performance of wind velocity and turbine component mean temperature based on different ambient temperatures

Once, the mean temperature profile is ready, the next task is to record and compare the heat mapping for each wind turbine component. The excellent benefit of this method is to develop component level heat profile for different climatic conditions which can be utilized for turbine maintenance, future turbine design with consideration of heat impact. This heat mapping is shown in Figure 12, Figure 13 and Figure 14 for winter, summer and rainy season respectively.

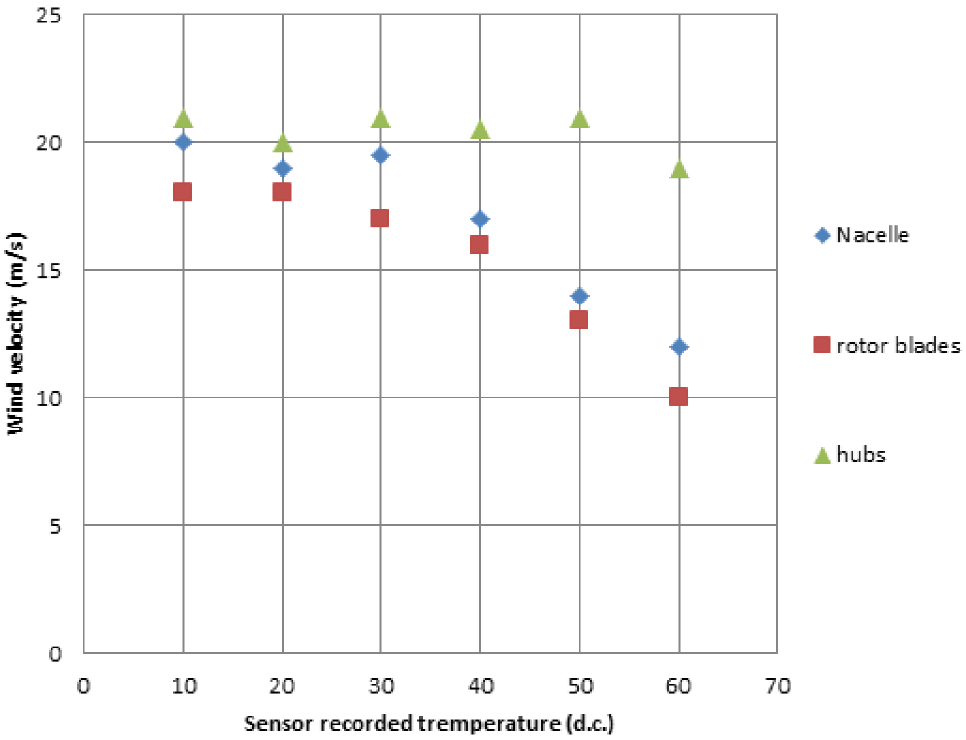

Fig. 12. Individual wind turbine component heat mapping for winter

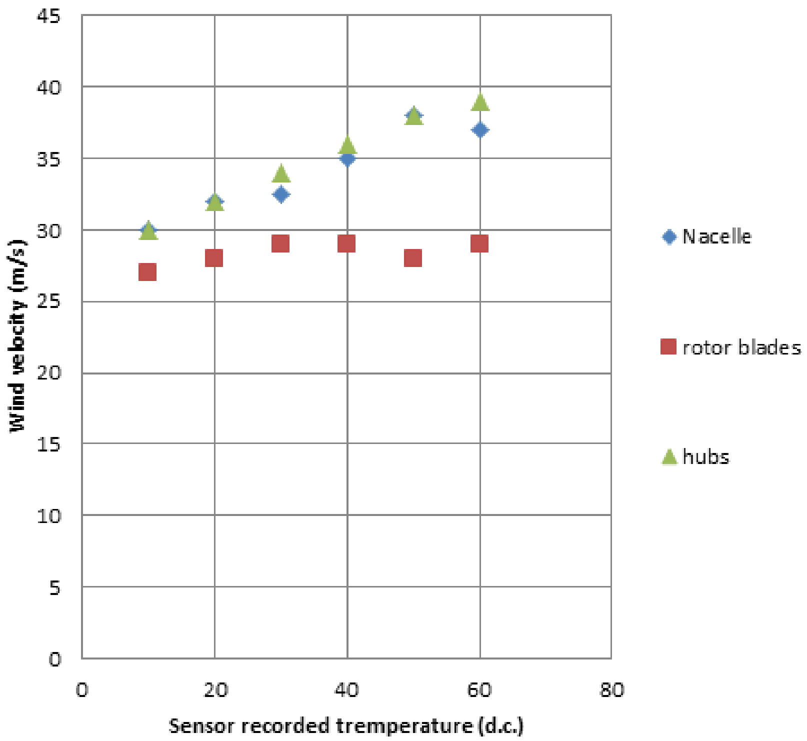

Fig. 13. Individual wind turbine component heat mapping for summer

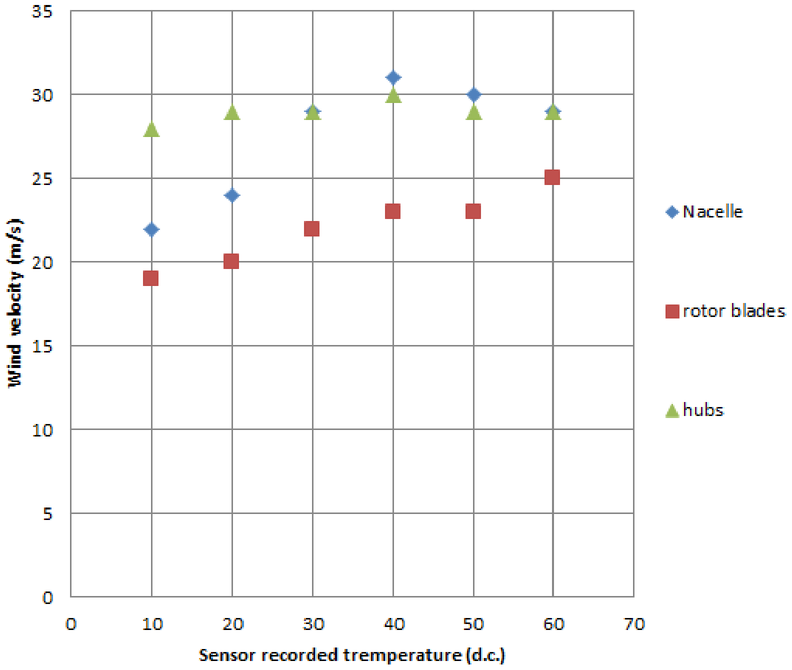

Fig. 14. Individual wind turbine component heat mapping for rainy climates

The above optimization of individual wind turbine component heat mapping for 3 climatic conditions is limited to the single wind turbine components and the result of heat generation and transfer of heat to other correlated mechanical components. These heat observations are based on the real time observations for period of one year. Steady state working conditions are assumed in terms of any mechanical failure with variable wind velocity. With this way of execution, we are able to focus research in the field of heat mapping which supports the theoretical aspects with real time implementation which can be used for the future design of high-performance, reliable and economic wind turbines with mechanical failure prediction.

4. Conclusions

A temperature gets heat transfer by conduction internally, concurrently; there is certainly vitality exchange by convection straight into environment or other nearby components through its surface area. The heat conduction associated with an object establishes how much heat it exchanges. Growing the temperatures variation between mechanical components as well as the surroundings, growing the outer lining section of the component boosts the heat transfer. The suggested analyze demonstrated the significance of heat transfer evaluation to offer the best overall performance of wind turbine components. The effect of heat on each and every mechanical component along with seasonal change in ecological temperature is important element. Wind rose methodology is thus useful with sensor implantation for any mechanical heat transfer study for identification of heat variance study with lower cost investment. Also, the sensor implantation technique is best for development of mechanical component level heat profiles, which can be used for future turbine design and also for CFD analysis. It analyses the influence of mechanical part temperatures on energy generation, highlighting how high temperatures can indicate component deterioration, such as bearing damage. Notably, the study focuses on wind speeds ranging from 10 to 15 m/s, a typical operational range for wind turbines. As heat transfer coefficient increases the wind turbine performance decrease. The heat transfer rate decreases 14.28% from rainy to winter season and 42.85% from winter to summer season. The wind rose analysis provides valuable insights into wind patterns and characteristics at a specific location, which can inform decision-making in various fields such as energy, construction, environmental management, and safety planning. As the turbine temperature increases the wind velocity decreases. It decreases 28 % from rainy to winter season.

References

[1] Carotenuto, Alberto, Pasquale Marotta, Nicola Massarotti, Alessandro Mauro, and Gennaro Normino. "Energy piles for ground source heat pump applications: Comparison of heat transfer performance for different design and operating parameters." *Applied Thermal Engineering* 124 (2017): 1492-1504. https://doi.org/10.1016/j.applthermaleng.2017.06.038

[2] Cao, Qi, Xingqing Yan, Xiaolu Guo, Hailong Zhu, Shaorong Liu, and Jiangliang Yu. "Temperature evolution and heat transfer during the release of CO_2 from a large-scale pipeline." *International Journal of Greenhouse Gas Control* 74 (2018): 40-48. https://doi.org/10.1016/j.ijggc.2018.04.015

[3] Nilsson, Martin. "The European Union and global climate change." In *Climate Change, Policy and Security*, pp. 131-149. Routledge, 2018. https://doi.org/10.4324/9781351060479-6

[4] Fino, Rosário, António Tadeu, and Nuno Simões. "Influence of a period of wet weather on the heat transfer across a wall covered with uncoated medium density expanded cork." *Energy and Buildings* 165 (2018): 118-131. https://doi.org/10.1016/j.enbuild.2018.01.020

[5] Kuznetsov, G. V., K. Yu Osipov, M. V. Piskunov, and R. S. Volkov. "Experimental research of radiative heat transfer in a water film." *International Journal of Heat and Mass Transfer* 117 (2018): 1075-1082. https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.082

[6] Li, Zengrui, and Zhigang Zhang. "Dynamic heat transfer characteristics of wall implanted with heat pipes in summer." *Energy and Buildings* 170 (2018): 40-46. https://doi.org/10.1016/j.enbuild.2018.03.071

[7] Sun, X. Y., Y. J. Dai, T. S. Ge, Y. Zhao, and R. Z. Wang. "Investigation on humidification effect of desiccant coated heat exchanger for improving indoor humidity environment in winter." *Energy and Buildings* 165 (2018): 1-14. https://doi.org/10.1016/j.enbuild.2018.01.047

[8] Gai, Yaohui, Mohammad Kimiabeigi, Yew Chuan Chong, James D. Widmer, James Goss, Unai SanAndres, Andy Steven, and Dave A. Staton. "On the measurement and modeling of the heat transfer coefficient of a hollow-shaft

rotary cooling system for a traction motor." *IEEE Transactions on Industry Applications* 54, no. 6 (2018): 5978-5987. https://doi.org/10.1109/TIA.2018.2860558

[9] Lehmann, Robert, Quentin Werner, Norbert Neidig, and Frank Gauterin. "Thermal modelling of electric machine during the early development phase." In *17. Internationales Stuttgarter Symposium: Automobil-und Motorentechnik*, pp. 331-343. Springer Fachmedien Wiesbaden, 2017. https://doi.org/10.1007/978-3-658-16988-6_29

[10] Gholamalizadeh, Ehsan, and Jae Dong Chung. "Analysis of fluid flow and heat transfer on a solar updraft tower power plant coupled with a wind turbine using computational fluid dynamics." *Applied Thermal Engineering* 126 (2017): 548-558. https://doi.org/10.1016/j.applthermaleng.2017.07.192

[11] Qayyum, Sajid, Tasawar Hayat, Sabir Ali Shehzad, and Ahmed Alsaedi. "Mixed convection and heat generation/absorption aspects in MHD flow of tangent-hyperbolic nanoliquid with Newtonian heat/mass transfer." *Radiation Physics and Chemistry* 144 (2018): 396-404. https://doi.org/10.1016/j.radphyschem.2017.10.002

[12] Nazari, Mohammad Alhuyi, Roghayeh Ghasempour, Mohammad Hossein Ahmadi, Gholamreza Heydarian, and Mohammad Behshad Shafii. "Experimental investigation of graphene oxide nanofluid on heat transfer enhancement of pulsating heat pipe." *International Communications in Heat and Mass Transfer* 91 (2018): 90-94. https://doi.org/10.1016/j.icheatmasstransfer.2017.12.006

[13] Mourad, Abdel-Hamid I., Abdulla Almomani, Irfan Ahmad Sheikh, and Ammar H. Elsheikh. "Failure analysis of gas and wind turbine blades: A review." *Engineering Failure Analysis* 146 (2023): 107107. https://doi.org/10.1016/j.engfailanal.2023.107107

[14] Alami, Abdul Hai, Montaser Mahmoud, Haya Aljaghoub, Ayman Mdallal, Mohammad Ali Abdelkareem, Siti Kartom Kamarudin, and Abdul Ghani Olabi. "Progress in 3D printing in wind energy and its role in achieving sustainability." *International Journal of Thermofluids* 20 (2023): 100496. https://doi.org/10.1016/j.ijft.2023.100496

[15] Poddaeva, Olga, and Anastasia Fedosova. "Extreme wind speeds analysis using extended wind rose based on statistic methods." *Energy Reports* 8 (2022): 1177-1184. https://doi.org/10.1016/j.egyr.2022.07.103

[16] Arteaga-López, Ernesto, and César Angeles-Camacho. "Innovative virtual computational domain based on wind rose diagrams for micrositing small wind turbines." *Energy* 220 (2021): 119701. https://doi.org/10.1016/j.energy.2020.119701

[17] Kurhade, Anant Sidhappa, T. Venkateswara Rao, V. K. Mathew, and Naveen G. Patil. "Effect of thermal conductivity of substrate board for temperature control of electronic components: A numerical study." *International Journal of Modern Physics C* 32, no. 10 (2021): 2150132. https://doi.org/10.1142/S0129183121501321

[18] Kurhade, Anant, Virendra Talele, T. Venkateswara Rao, Archana Chandak, and V. K. Mathew. "Computational study of PCM cooling for electronic circuit of smart-phone." *Materials Today: Proceedings* 47 (2021): 3171-3176. https://doi.org/10.1016/j.matpr.2021.06.284

[19] Kurhade, Anant Sidhappa, and G. Murali. "Thermal control of IC chips using phase change material: A CFD investigation." *International Journal of Modern Physics C* 33, no. 12 (2022): 2250159. https://doi.org/10.1142/S0129183122501595

[20] Kurhade, Anant Sidhappa, G. Murali, and T. Venkateswara Rao. "CFD Approach for Thermal Management to Enhance the Reliability of IC Chips." *International Journal of Engineering Trends and Technology* 71, no. 3 (2023): 65-72. https://doi.org/10.14445/22315381/IJETT-V71I3P208

[21] Patil, Suhas Prakashrao, Sandeep Sadashiv Kore, Satish Suresh Chinchanikar, and Shital Yashwant Waware. "Characterization and Machinability Studies of Aluminium-based Hybrid Metal Matrix Composites-A Critical Review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 2 (2023): 137-163. https://doi.org/10.37934/arfmts.101.2.137163

[22] Waware, Shital Yashwant, Sandeep Sadashiv Kore, and Suhas Prakashrao Patil. "Heat Transfer Enhancement in Tubular Heat Exchanger with Jet Impingement: A Review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 2 (2023): 8-25. https://doi.org/10.37934/arfmts.101.2.825

[23] Waware, Shital Yashwant, Sandeep Sadashiv Kore, Anant Sidhappa Kurhade, and Suhas Prakashrao Patil. "Innovative Heat Transfer Enhancement in Tubular Heat Exchanger: An Experimental Investigation with Minijet Impingement." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 116, no. 2 (2024): 51-58. https://doi.org/10.37934/arfmts.116.2.5158

[24] Khot Rahul, S., and Prasanna Rajendra Kadam. "Structural Behavior of Fillet Weld Joint for Bimetallic Curved Plate Using Finite Element Analysis (FEA)." In *6th International Conference on Advanced Research in Arts, Science, Engineering & Technology, ICARASET - 2021 Proceedings*, Organized by DK International Research Foundation, pp. 23-28. 2021.

[25] Khot Rahul, S., and T. Venkateswara Rao. "Investigation of mechanical behaviour of laser welded butt joint of transformed induced plasticity (TRIP) steel with effect laser incident angle." *International Journal of Engineering Research and Technology* 13, no. 11 (2020): 3398-3403. https://doi.org/10.37624/IJERT/13.11.2020.3398-3403

[26] Khot Rahul, S., T. Venkateswara Rao, Harshad Natu, H. N. Girish, Tadashi Ishigaki, and Puttaswamy Madhusudan. "An Investigation on Laser Welding Parameters on the Strength of TRIP Steel." *Journal of Mechanical Engineering/Strojniški Vestnik* 67, no. 1/2 (2021): 45-52. https://doi.org/10.5545/sv-jme.2020.6912

[27] Khot Rahul, S., and T. Venkateswara Rao. "Effect of Quenching Media on Laser butt Welded Joint on Transformed -Induced Plasticity (TRIP) Steel." *International Journal of Emerging Trends in Engineering Research* 8, no. 10 (2020): 7686-7691. https://doi.org/10.30534/ijeter/2020/1588102020

[28] Khot Rahul, S., T. Venkateswara Rao, Abhishek Keskar, H. N. Girish, and Puttaswamy Madhusudan. "Investigation on the effect of power and velocity of laser beam welding on the butt weld joint on TRIP steel." *Journal of Laser Applications* 32, no. 1 (2020): 012016. https://doi.org/10.2351/1.5133158

[29] Gadekar, Tushar D., Dinesh N. Kamble, and Nitin H. Ambhore. "Experimental Study on Gear EP Lubricant Mixed with $Al_2O_3/SiO_2/ZrO_2$ Composite Additives to Design a Predictive System." *Tribology in Industry* 45, no. 4 (2023): 579. https://doi.org/10.24874/ti.1461.03.23.07

[30] Gadekar, Tushar, and Dinesh Kamble. "Tribological investigation on oil blended with Additive using Response surface methodology." In *E3S Web of Conferences*, vol. 170, p. 01025. EDP Sciences, 2020. https://doi.org/10.1051/e3sconf/202017001025

[31] Kamble, Dinesh N., Tushar D. Gadekar, and Devendra P. Agrawal. "Experimental study on gearbox oil blended with composite additives." *Jurnal Tribologi* 33 (2022): 1-19.

[32] Patil, Prashant, Nitin Kardekar, Rahul Yadav, Anant Kurhade, and Dhanapal Kamble. "Nanofluids: An Experimental Study for MQL Grinding." *Journal of Mines, Metals and Fuels* 71, no. 12 (2023): 2751-2756. https://doi.org/10.18311/jmmf/2023/41766

[33] Poddaeva, Olga, and Anastasia Fedosova. "Extreme wind speeds analysis using extended wind rose based on statistic methods." *Energy Reports* 8 (2022): 1177-1184. https://doi.org/10.1016/j.egyr.2022.07.103

[34] Diaz, Gonzalo P. Navarro, A. Celeste Saulo, and Alejandro D. Otero. "Full wind rose wind farm simulation including wake and terrain effects for energy yield assessment." *Energy* 237 (2021): 121642. https://doi.org/10.1016/j.energy.2021.121642

[35] Arteaga-López, Ernesto, and César Angeles-Camacho. "Innovative virtual computational domain based on wind rose diagrams for micrositing small wind turbines." *Energy* 220 (2021): 119701. https://doi.org/10.1016/j.energy.2020.119701