DFIG integration with ReLIFT converter for grid-connected systems: ANFIS MPPT control

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Article Info

Article history:

Received Jul 8, 2024
Revised Jun 28, 2025
Accepted Aug 6, 2025

Keywords:

ANFIS controller
Doubly fed induction generator
Grid integration
Maximum power point tracking
ReLIFT converter
Transformer losses

ABSTRACT

Although dispersed generation and non-linear loads provide difficulties for contemporary power systems that depend on power electronics, renewable energy sources (RES) are essential for meeting the world's energy demands. This paper provides a unique method for maximum power point tracking (MPPT) in doubly fed induction generators (DFIG) system using an Adaptive network based fuzzy inference system (ANFIS) inference system. The suggested ANFIS MPPT controller adaptively modifies discontinuous control gain to reduce chattering phenomena in the excitation system while preserving the resilience of the closed-loop system. Prior to using a DQ control theory controller for rotor magnitude adjustment to accomplish vector control of active and reactive power, the turbine and DFIG must be modeled. The converter maximizes output current while striving for unity power factor and allowable harmonic content.

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1. INTRODUCTION

In recent years, renewable energy systems, especially those that use wind power—have attracted a lot of interest as a viable way to fulfill the world's expanding energy needs. Among these systems, a complex method for the effective use of wind energy resources is the integration of doubly fed induction generators (DFIGs) with grid-connected installations. Because of its special capacity to control power separately, DFIGs are a top option for wind turbine applications. Rectifier and inverter (ReLIFT) converters [1], [2] are used to interface the generator's variable frequency output with the standardized frequency and voltage levels needed for synchronization with the main power grid, thereby facilitating the integration of DFIGs with grid-connected systems. This integration adds to the total mix of renewable energy sources (RES) by facilitating the smooth transit of generated electrical power to the grid.

However, efficient control procedures are necessary to maximize power extraction from shifting wind conditions and to optimize the performance of DFIG-based wind energy systems. It's possible that conventional maximum power point tracking (MPPT) methods won't be able to adjust to changing environmental conditions [3], [4]. Therefore, it is essential to use an intelligent control system for MPPT control, such as the adaptive network based fuzzy inference system (ANFIS) inference system. In light of this, this research suggests an ANFIS-based MPPT control approach for wind energy systems based DFIG that are coupled with ReLIFT converters. The main goal is to increase the overall efficiency and dependability of grid-connected wind energy systems by tracking the maximum power point under variable wind speeds by dynamically modifying the converter's operational settings.

By addressing the difficulties with grid integration and control mechanisms, this study seeks to further the current research efforts in the field of renewable energy systems and, in the end, promote the broad use of wind energy as a practical and sustainable power source. The effectiveness of the suggested ANFIS-based control strategy will be shown by thorough simulations and analysis, underscoring its potential for maximizing power generation and grid synchronization in DFIG-based [5], [6] wind energy systems. Relevant publications addressing DFIG integration, ReLIFT converter applications, and advanced control methodologies for wind energy systems will be mentioned and addressed in order to place this study within the current body of literature.

2. RESEARCH METHOD

A DFIG that produces wind energy using a wind turbine with variable speed. The two DFIG controllers can generate and keep track of power using the rotor side converter (RSC) and grid side converter (GSC) and maintain a constant rotor velocity. With its very steady and sophisticated control technology, the DFIG-based windmill is currently the most popular form of wind turbine. Furthermore, optimizing the MPPT of DFIG-based wind mills is crucial to raising their wind power conversion efficiency. Wind energy is generated with a DFIG that depends on speed of wind turbine. The two DFIG controllers, the RSC [7], [8] and GRS, are able to generate and track reactive power in addition to maintaining a steady rotor velocity. The most popular wind turbines right now are DFIG-based windmills due to their advanced control and stability technologies. Moreover, a key factor in raising the efficiency of wind power conversion is the MPPT of windmills based on DFIG.

In order to maximize the performance of DFIG, efficient MPPT algorithms are necessary to reliably identify and maintain the MPP under wind conditions is shown in Figure 1. It is coupled to the 3φ voltage source inverter (VSI) and controls the pulse width modulation (PWM) pulses. The ANFIS MPPT monitors the output voltage and current, and it also generates PWM pulses that are linked to the ReLIFT converter. PI controller [9], [10] is used in this work to keep the dc-link voltage constant. By controlling and stabilizing the dc-link voltage within the intended range, the usage of a PI controller enhances the overall performance and stability of the system in question. The LC filter receives the output from the 3φ VSI and supplies it to the 3φ grid.

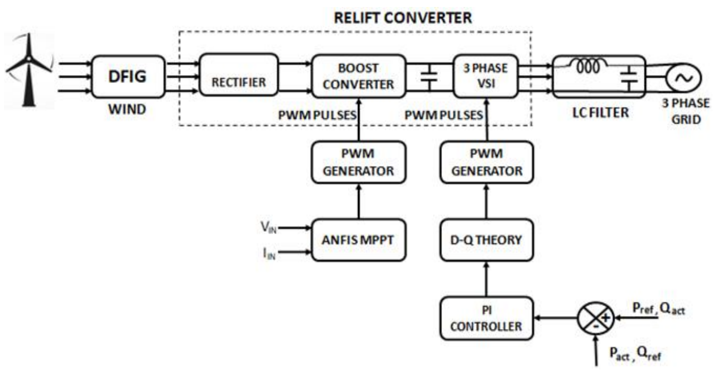

Figure 1. Proposed system block diagram

2.1. Advantages of research method

The advantages of the research method include high system efficiency, which ensures optimal performance with minimal resource wastage, leading to cost reductions across various operational aspects. By eliminating transformer losses, the method enhances energy conservation and performance, ensuring that power is transmitted without significant dissipation. Additionally, the system maintains a constant output voltage on the utility side, providing stability and reliability for connected devices, which is crucial in avoiding damage or inefficiencies. Overall, this method leads to a more cost-effective and reliable solution, with significant improvements in both energy management and system performance.

2.2. ReLIFT converter

It's possible that the word "ReLIFT converter" [11], [12] hasn't become well-known or established in the fields of power electronics or renewable energy systems. It's conceivable, though, that since then, developments or new terms have appeared in the area. In order to enable effective power transmission and usage in power electronics and renewable energy systems, converters are necessary for converting electrical energy between various forms. The word "ReLIFT converter" might refer to a particular application that surfaced since my previous update, private technology, or an abbreviation or specific naming pattern utilized in recent study.

It could also be a special modification or adaption of an already-existing converter topology designed to serve a specific function. Generally speaking, converters in renewable energy systems have a number of uses, including: [13], [14]. To provide AC loads or connect to the grid, utilize inverters to convert DC to AC. Control of voltage and frequency modifying voltage and frequency levels to correspond with loads or grid needs. Enhancing power quality means making sure that linked loads or the grid receive consistent, high-quality power supply. If this phrase has originated or acquired significance in the sector since my previous update, it is imperative to examine the most recent literature, research papers, or industry sources to understand the precise properties, functions, and applications of ReLIFT converters. I would be happy to help further based on any specific information you may have if it relates to ReLIFT converters [15], [16], their use, or a specific application.

In the event that the "ReLIFT converter" is a novel or exclusive technological advancement, it can possess unique characteristics or operational principles designed to maximize particular facets of power conversion, grid integration, or enhancing efficiency in renewable energy systems. Technical material pertaining to this particular technology or converter architecture, as well as current research articles and patents [17], [18], are likely to include detailed information about how it operates. Three layers make up the ReLIFT converter. They are as follows:

Figure 2 represents the using rectifier generated AC is converted into DC and given to the boost converter. Figure 3 represents the use of boost converter will receive the converted DC power and it will step up the received DC power. Figure 4 represents the use of three phase VSI will convert step up DC into regulated (synchronised) voltage, which is then given to the grid.

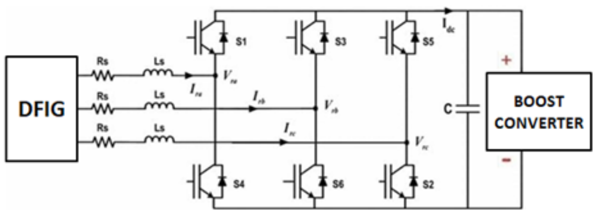

Figure 2. Circuit diagram of ReLIFT converter

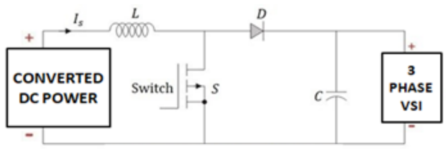

Figure 3. Circuit diagram of ReLIFT converter (layer - 2)

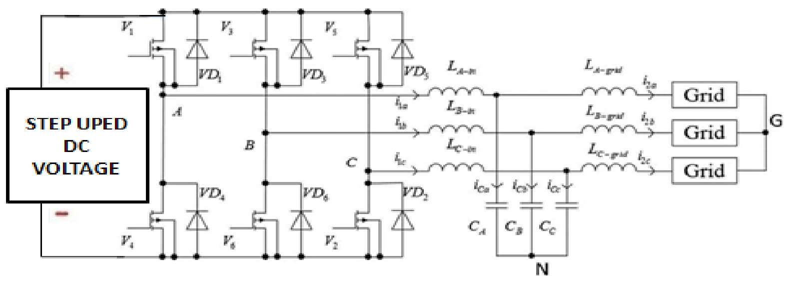

Figure 4. Circuit diagram of ReLIFT converter (layer - 3)

2.3. PI controller

There are several methods for designing PI controllers in control systems [19], [20]. Static Output Feedback is the method that may be used on the controller to achieve global stability among various methods. As seen in Figure 5, the error between the measured value y from the plant and the set point Yo serves as the input to the PI controller. Output of the controller, u may be expressed as:

$$u = kp\,Yo + ki \int Yo\,dt \quad (1)$$

where, kp and ki are controller constants.

In (1) can be rewritten as,

$$u = [\, kp\; ki\,][\, Yo \int Yo\,]^T \tag{2}$$

therefore, measured output can be,

$$y = [\, Yo \int Yo\,]^T \tag{3}$$

and PI controller can be described as,

$$Gc = [\, kp\; ki\,] \tag{4}$$

two linked linear matrix inequalities are used in the construction of the PI controller based on the SOF technique. Static output feedback controllers are used to modify the PI controller, resulting in an impulse-free and stochastically stable closed-loop system Boukas [10]. The calculated PI values are ki = 4.6647 and kp = 0.0814.

2.4. GSC control system

Figure 6 illustrates the GSC, which is used to control the DC bus capacitor's voltage, d-axis of the rotat reference utilized for the d-q transformation for the GS controller [21], [22] is in line with the grid voltage's positive sequence.

1. The DC voltage Vdc in addition, the d and q components of the AC currents that need to be managed.
2. A DC voltage regulator makes up the outer regulating loop.
3. The voltage created by the GSC is controlled by the current regulator. It is derived from the Idgc ref, which is produced by the DC voltage regulator, and a set Iq reference.

DQ theory is designed to regulate the power between the generator and the grid. DQ theory, also known as the Park transformation, is commonly used in control systems for AC machines like induction generators to simplify the control of AC systems.

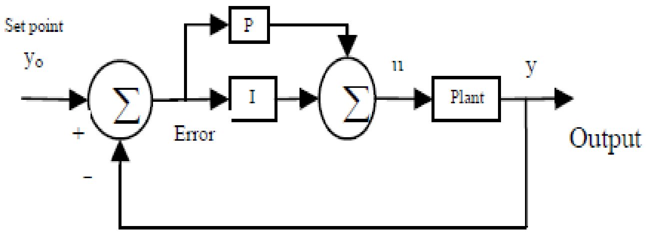

Figure 5. PI Controller in closed loop system

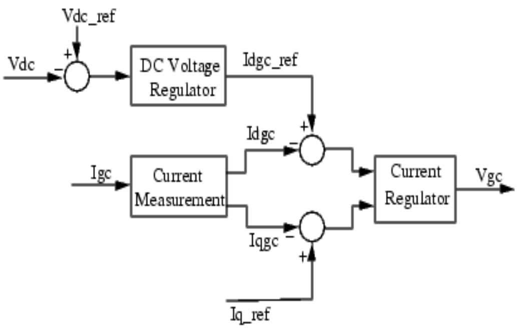

Figure 6. GSC control

2.5. ANFIS

The ANFIS inference technique effectively combines the concepts of artificial neural networks with fuzzy control [23], [24]. Fuzzy logic and neural networks work together to make it a better translator and learner [25]. The main architecture of ANFIS consists of five tiers, as shown in Figure 7.

First layer	:	MF and user-specified input variables make up the adaptive fuzzification layer
Second layer	:	After determining the degree of MF, chooses and feeds the matched fuzzy set to the next layer.
Third layer	:	The weight of every normalized node is established by third layer.
Forth layer	:	Every neuron is normalized by the forth layer, which produces values based on inference rules.
Fifth layer	:	To convert the fuzzy values into a crisp value, the output layer mixes together all of the inputs from forth layer.

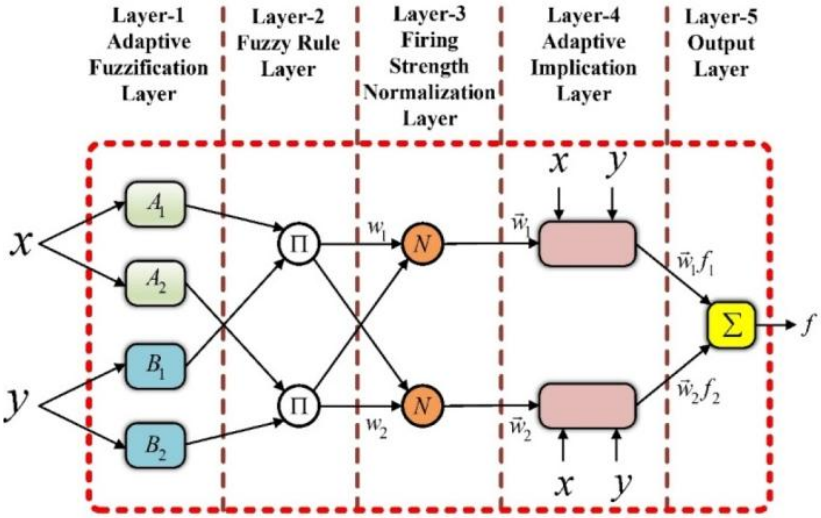

Figure 7. ANFIS

3. RESULTS AND DISCUSSION

Using an ANFIS controller method and a grid-connected SPWM voltage source inverter at the output, MATLAB Simulink was used to create the simulation model for the DFIG with Re-lift converter fed grid-connected system, as shown in the Figure 8 and its turbine section is as shown in Figure 9.

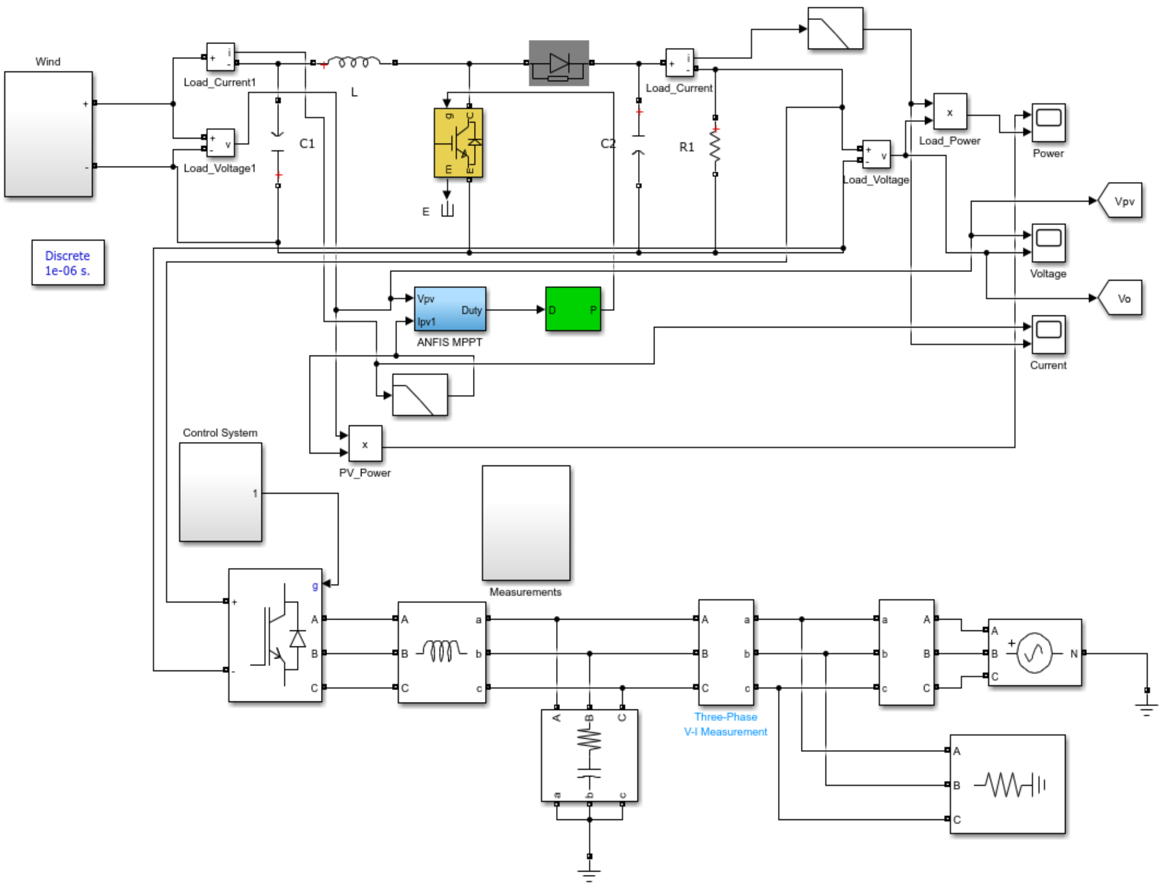

Figure 8. ANFIS MPPT simulink mode

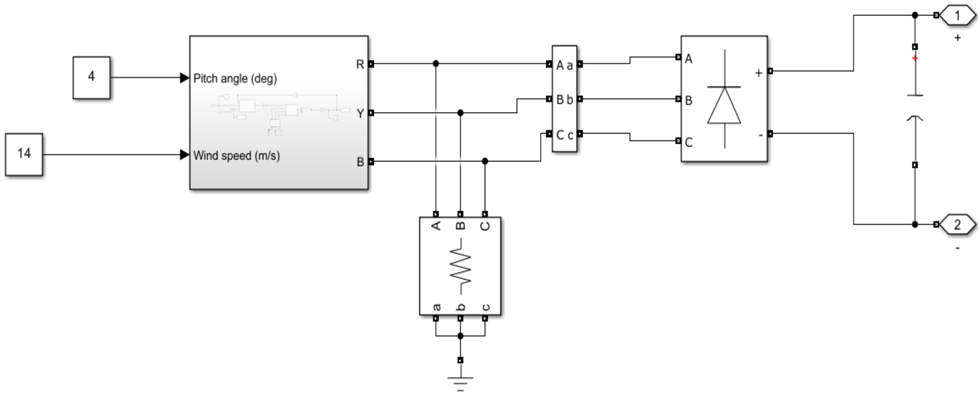

Figure 9. Turbine section

The (5) represents the quantity of electricity that the wind turbine generates.

$$P_t = \frac{1}{2}\rho\pi R^2 V_v^3 C_p(\lambda, \beta) \tag{5}$$

Where represents the air density in kilograms per cubic meter (kg/m3), R is the turbine's rotor radius in meters (m), Vv shows the wind speed in meters per second (m/s), and $Cp(\lambda,\beta)$ represents the power coefficient as a function of pitch angle (β) and tip-speed ratio (λ). (6) is an expression for λ.

$$\lambda = \frac{R\omega_t}{V_v} \tag{6}$$

Where vt is the wind turbine rotor's angular rotational speed (rad/sec). In (7) expresses $Cp(\lambda,\beta)$.

$$C_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\beta^{c_5} - c_6\right).e^{\frac{-c_7}{\lambda_i}} \tag{7}$$

λ_i is given in (8):

$$\lambda_i = \frac{1}{\lambda+0.02\beta} - \frac{0.003}{\beta^3+1} \tag{8}$$

the turbine generated torque is expressed in (9).

$$T_t = \frac{P_t}{\omega_t} \tag{9}$$

The output screenshots of the findings with the produced voltage and enhanced voltage are shown in Figures 10 and 11. The boosted voltage is 1500V, whereas the measured produced voltage is 700V. Consequently, the power level of the input vs. output curves may be seen to lie within an MPPT operational range.

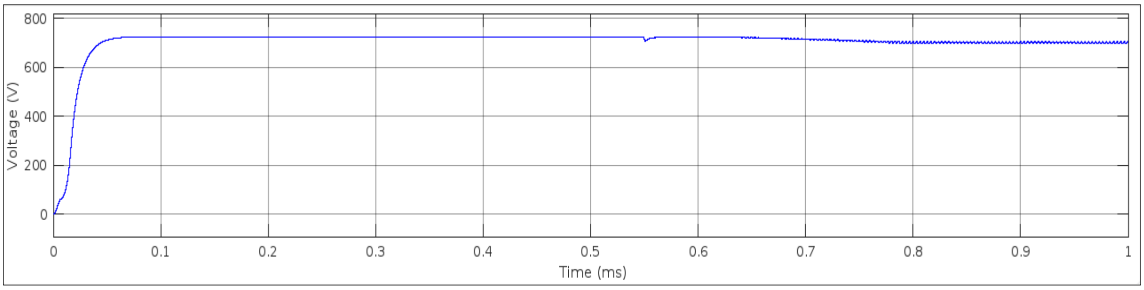

Figure 10. Generated voltage

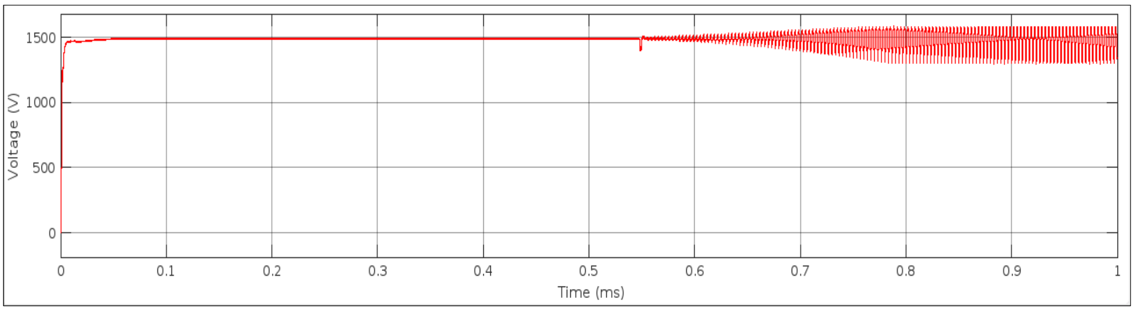

Figure 11. Boosted voltage

4. CONCLUSION

To maximize the power from wind energy sources, this study concludes with a novel wind conversion system architecture that uses the ReLIFT conversion in intergration with an ANFIS MPPT algorithm. The suggested system exhibits exceptional efficiency in wind power utilization by using a three-phase VSI to change fixed DC voltage to variable frequency AC voltage and by using PI-based D-Q theory for reference current extraction and reactive energy minimization. The best possible use of wind resources is ensured by integrating a rectifier to convert the wind turbine's alternating current output to direct current, which is then routed into the MPPT system. DQ theory is used to align the inverter output current with the injected grid voltage, achieving grid synchronization. With an MPPT efficiency of 88%, the MATLAB results demonstrate the usefulness of the suggested system and show a notable improvement over conventional control systems. This research advances the knowledge and use of grid-connected wind energy conversion systems by offering a thorough assessment of the suggested architecture and control schemes. The study's conclusions not only validate earlier discoveries in the area but also open the door for further developments in renewable energy systems, which will eventually aid in the shift to a sustainable energy future.

FUNDING INFORMATION

This research received no external funding.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Chidambararaj Natarajan	✓			✓	✓		✓			✓	✓	✓		
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Siva Malavan Elantherayan Sharmila			✓		✓	✓	✓		✓	✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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