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ORIGINAL PAPER

Analysis of Power Loss in Forward Converter Transformer Using a Novel Machine Learning Based Optimization Framework

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Abstract

High power and high voltage gains in Forward Converter significance are a foremost topic for wind power switch mode supplies. However, due to the recent penetration of forward converter usage in the power network and wide range of load, the reliability and power loss problem becomes a crucial one. Therefore, this paper projected a novel Grey Wolf based Boosting Intelligent Frame (GWbBIF) control algorithm for improving the reliability of power system since the incorporation of forward converter to the entire system level. Consequently, the power loss of transformer is optimized by the projected Grey Wolf fitness function. The implementation of this work has been done on MATLAB/Simulink. The simulation outcomes of the proposed system show that the forward converter reliability and power loss of transformer are considered as significant aspects while estimating the whole system function. The proposed outcomes are compared with the conventional methods for validating the importance of the projected method.

Keywords Forward converter · Machine learning · Optimization · Power loss · Transformer · Wind system

Nomenclature

D'	Utmost duty cycle of the pulse width modulator.
N_s' and N_p'	Turns quantity of the secondary and primary winding.
ε, φ, γ and κ	Gain parameters.
$\overrightarrow{B}$ and $\overrightarrow{D}$	The coefficient of vectors.
$\overrightarrow{Y}_q(s)$	The location vector of error.
s	Present iteration.
$\overrightarrow{Y}$	The location vector of duty cycle.
$\overrightarrow{E}$	The observed duty cycle.
$\overrightarrow{t}_1$ and $\overrightarrow{t}_2$	The arbitrary vectors that belong to (0, 1).
$\overrightarrow{b}$	The vector element.
M	Weights of the error.
n	Number of weights.
k	The initialization value.
I	The learning parameter.
c	The constant vector.
e^j	The position of error.
σ^j	The coefficient of the duty cycle vector locations.
Z	The training sequence.
g	Predicted error value.
$\overrightarrow{Y}_1$, $\overrightarrow{Y}_2$, and $\overrightarrow{Y}$	The fitness values.
P_ε, P_φ and P_κ	The overall weights of the transformer.

Introduction

The rapid development of converter penetration in power system might increase the advancement of power electric-based applications [11]. However, the estimation of power

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transformer issues is the basic need for an effective transformer application [28]. In addition, the smart design of the power system frame is designed with the support of solar photovoltaic renewable energy sources [19]. Several circuits and schemes are available to build an effective power supply in power transmission applications [5]. The chief reason for developing the reliability estimation frame in power electronics application is to enhance the system-level performance [18]. Moreover, from the transformer performance analysis, the function of transformer and its difficulty scores are listed in detail [29]. Hereafter, a suitable approach is utilized to improve the transformer function and fault avoidance [32]. Furthermore, in the power system, the forward converter is a more proficient paradigm than other conventional converters [20, 21]. Hence, it has high rapidity switching gadgets that are mainly integrated with transformer applications [22].

Eventually, the prime side of transformer is fixed to the regulator circuit, and the subordinate side of the transformer is linked to the straining circuit [7]. Finally, the resolved secondary winding transformer output is linked with loads [8]. Here, if the switch is remained in ON condition, then the input constraints have functioned in the transformer prime winding [13], and the source of voltage is flown in subordinate windings [20, 21]. In addition, the transformer output voltage is nourished to the squat pass sift circuit frame [24]. Moreover, the forward converter is utilized in wind turbine transformer to improve the performance of wind system generators. Because of the simple configuration, the forward converter system is normally placed for medium and low power applications. For power switching operation in the lower area, gate drivers are the significant merits of forward converter [17]. The usage of conventional power converters in transformers often causes power faults, so that system can shut down at any time. Also, the fault in converters needs more power to execute the transformer function. Thus the computational cost and loss of power are maximized, which leads to poor transformer performers [12]. So, the forward converter is introduced in the power system applications to improve its efficiency and advancements.

Usually, the function of transformer is always depends upon its fixed converter. In a forward converter, the prime and subordinate windings need ultimate current than conventional converters to execute the function [25]. Thus the loss of power in transformer has considerably reduced [31]. Nevertheless, the high amount of leakage inductance, simulated transformer voltage and input voltage can tend to create more amount of voltage stress over the power switches in the forward converter [15]. Also, in some unbalanced load conditions, power loss has occurred [16], for that optimization framework is needed to optimize the transformer performance by diminishing the power loss rate [26]. Numerous methods are introduced like hierarchical frame and Machine Learning (ML) [33], power topology [9], power tracing frame [3], Proportional Integral Derivative (PID) method, Deep learning method [30], Multivariable digital PID technique [1], Hybrid k-means based Grasshopper algorithm [2] etc., to optimize the transformer and converter faults. However, in some complicated cases, these methods are failed to meet the objectives. The duty cycle rate of forward converter is not to meet the essential level of output voltage regulation.

Moreover, the estimation of system and converter reliability is the important function parameter to improve the transformer function in each power application. These issues and applications motivated this research toward optimized ML with forward converter in the wind energy system. Therefore, in this research, a novel GWBIF control method is proposed in the forward converter. The GWBIF method is the hybrid combination of grey wolf and boosting algorithm. The finest duty cycle of the forward converter for voltage regulation is optimized using the fitness of GWBIF method. Thus, the voltage stress over the power switches is reduced by the proposed method. Consequently, power loss in the transformer is also optimized by the proposed method. The reliability and stability of the projected design are validated. At last, the performance of the proposed method is compared with the conventional methods in terms of power loss, stability, THD, etc.

The configuration of this paper is summarized below: The literature related to this work is explained in Section 2. In Section 3, the system model and problem statement are detailed. The proposed control method for the forward converter is described in Section 4. The result and discussion along with the comparison are explained in Section 5. Finally, in Section 6 ends the paper.

Related Works

The recent associated works based on different power converters model are detailed as follows:

In power electronics, estimation of system performance is the important paradigm to avoid function error. So, Zhang et al. [33] have developed a broad framework based on reliability hierarchical structure to analyse the function performance of transformer in the wind system. Also, that hierarchical frame includes the ML functions to make the assessment of system performance. Moreover, the projected frame is validated with the 24-IEEE bus system and has attained a better stability range. However, power loss is happed in a wide range during unbalanced load conditions.

Gruner et al. *[9]* have developed a novel power topology to improving input and output current sharing by the gain stability in forward DC converters. In addition, the efficiency of the designed model is evaluated under 1 kW prototype, also compared with other associated converters. Finally, the proposed frame has achieved optimized input current distribution and gain measure. But in some cases, this convert has attained wide flaw measure because of load variances.

On the other hand, the power tracking frame is a key role in the PV paradigm to obtain the finest power distribution efficiency. Thus, an improper power tracking scheme might lead to power loss and power system performance. So, Başoğlu [3] have planned a power tracing model based on perturb procedure with forward converter to improve the tracing behaviour in power tracking applications. Finally, the developed paradigm has gained 95.34% of power tracking measure. But the proposed structured model is high in cost.

The electronic converter is the intermediate frame for the battery system and power network. So, Habib et al. *[*10*]* have analysed recent trends and difficulties measure of power converters for diverse applications. Here, electric vehicle application is adopted to estimate the converter function. Henceforth, the outcome of the converters assessment has revealed the performance score of each converter. However, this analysis revealed that the main drawback in power converter is computational cost.

Li et al. *[*14*]* have designed a novel trapezoidal current frame to enhance the power converter switching performance. Thus, the investigation of specific PV gadget power loss is a significant factor. Moreover, the capacity of the projected converter is analysed using GAN gadget and compared with other conventional converters. From the assessment, the designed paradigm has obtained high sensitivity score over other methods. But it takes more time to complete the process.

The hybrid form of Fractional Order Proportional Integral Derivative (FOPID) controller and k-means based Grasshopper Optimization is developed by [2] for forward converter in renewables energy systems. The FAPID controller gain parameters are tuned by the optimization approach. The oscillation, convergence, ripples and rise time are also diminished by the developed method. However, the design of this approach is highly complex and unstable.

The core and size losses in the transformer are highly increased because of the high amount of dc offset current. For this reason, [12] developed a two-stage active clamp method of the forward converter. This method has attained less dc offset current in the place of transformer unit and reduces the outcome of inductor ripple current. Also, the efficiency of the system is highly improved, but the cost and convergence are moreover other methods [34] introduced an active-clamp based forward converter for high performance power supply units. Here, the standing slab based inductor is linked to the system; thus it achieved high saturation current and inductance. The dc loss and conversion loss is highly reduced by this developed model. However, the time taken for the processing is high and more error rate is created.

The Fitness Oriented Rider based Optimization Algorithm (FO-ROA) is created by [23] for power converters in hybrid power generating schemes. The hybrid wind and solar combination are considered for the power generation unit. Here, the possible THD values and power loss are significantly diminished. Moreover, the three stages of power quality problems in the power converter are regulated by the developed algorithm and improved the reliable performance of the system. Yet, the simulation time and cost is more.

The key function of this novel research work is described as follows,

- Initially, the model of transformer linked wind energy system is designed using MATLAB/Simulink platform.
- Consequently, a forward converter is designed and linked to the wind transformer.
- A novel GWBIF control method is proposed for the forward converter to improve the performance of the duty cycle.
- Also, the reliability of the system is measured and to optimize the transformer function.
- The fitness process of the grey wolf is utilized to optimize the power loss in transformer and to improve the stability range power.
- Finally, the attained outcome is compared with other existing methods in terms of power stability, error, power loss in different load condition, THD, simulation time, complexity, and current value.

System Model and Problem Statement

The design of forward converter is structured in Fig. 1. The forward converter is considered as the DC to DC converter that employs a transformer to raise or drop the output voltage based on the ratio of transformer and afford galvanic separation for the system load. Moreover, both lower as well as higher output voltage can be provided to the system simultaneously because, it has multiple output windings. In the course of switch conduction stage, the power flows straight to the forward converter outcome using the event of transformer. Moreover, the forward converter is considerably utilized in high outcome current based applications due to its

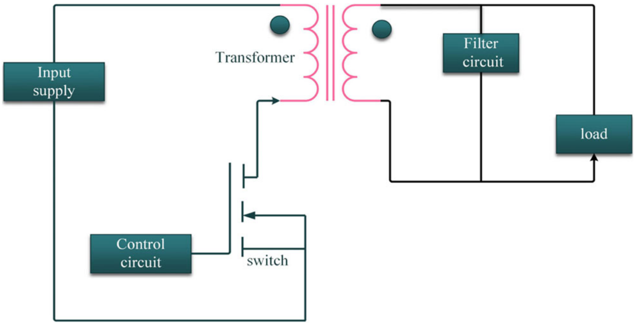

Fig. 1 System model design of forward converter

non-pulsating feature in current output. While turn ON the power switch, the power flow happens through the isolation transformer. At this time, the fundamental voltage is replicated to the winding of secondary side; also, this is corrected using the forward diode. Furthermore, corrected voltage is filtered and also stored in the section of capacitor and inductor of the circuit. The duty cycle has been incorporated; thus, the voltage outcome is proportional to the multiplication of the corrected duty ratio and outcome voltage.

The utmost voltage outcome of the forward converter is forced using the turn's ratio of the transformer, which is expressed by the Eq. (1),

$$\text{Outputvoltage} = D^{'}.\frac{N_s^{'}}{N_p^{'}}.\text{Inputsupply} \tag{1}$$

where, $N_s^{'}$ and $N_p^{'}$ are turns quantity of the secondary and primary winding. The utmost duty cycle of the pulse width modulator is represented as $D^{'}$. The output power from the wind system is based on the angle and speed of wind. These changes of results will cause power loss to the devices, and it leads to a high level of device failure. Consequently, the magnetizing inductance of transformer in forward converter is very high, and this tends to reduce the current of magnetizing. When the current inside the forward converter is increased, then the loss of transformer will more. Therefore, the loss of transformer should be minimized by the estimation of losses along with the ignorance of magnetizing current. Hence a proper control technique has been developed based on the combination of machine learning and optimization for forward converter in wind power coordination system.

Proposed GWBBIF Method in Wind System

The proposed system representation is illustrated in Fig. 2. The chief aim of this research work is to minimize the transformer power loss and to improve the stability range. Furthermore, to estimate the system reliability and transformer power loss optimization, a novel GWbBIF is designed using the MATLAB framework.

Moreover, wind application is adopted to validate the proficient score of the developed model. Consequently, to improve the wind transformer function, the forward converter is utilized. The purpose of using forward converter is to optimize the wind system power consumption. Henceforth, comparing other conventional converters, the forward converter needs less power to execute the system functions.

Design of GWbBIF Control Method

The proposed GWbBIF control method architecture in wind system is described in Fig. 3. The input supply voltage, real power from the wind plant system is applied to the proposed controller. Moreover, the duty cycle value for the forward converter and the load value are also initialized to the controller. Consider, the suitable gain solutions are represented as ε, φ and κ. The rest of the solution is denoted as γ. In this GWbBIF control method is guided by the gain parameters ε, φ and κ. The parameters are enclosed using Eq. (2).

$$\vec{Y}(s+1) = \overline{Y}_q(s) - \vec{B}.\overline{E} \tag{2}$$

$$\vec{E} = \left|\vec{D}.\overline{Y}_q(s) - \vec{Y}(s)\right| \tag{3}$$

where the coefficient of vectors are denoted as $\vec{B}$ and $\vec{D}$, the location vector of error is $\overline{Y}_q(s)$, the present iteration is represented as s, $\vec{E}$ is the observed duty cycle, and the location vector of duty cycle is denoted as $\vec{Y}$. Moreover, the $\vec{B}$ and $\vec{D}$ of vector coefficient is estimated by Eq. (4),

$$\vec{B} = 2\vec{b}.\vec{t}_1 - \vec{b} \tag{4}$$

$$\vec{D} = 2.\vec{t}_2 \tag{5}$$

Where the arbitrary vectors are represented as $\vec{t}_1$ and $\vec{t}_2$ that belong to (0, 1) also $\vec{b}$ is the vector element diminished from 2 to zero than the progress of iteration. The location of gain can renew its location based on the location of error. Various

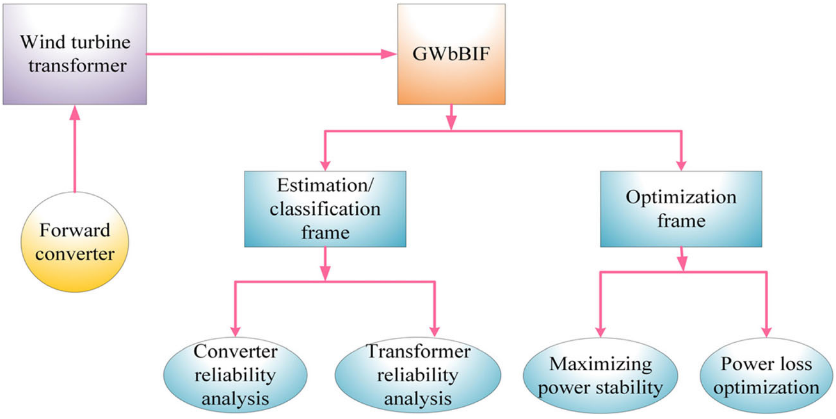

Fig. 2 Proposed System representation

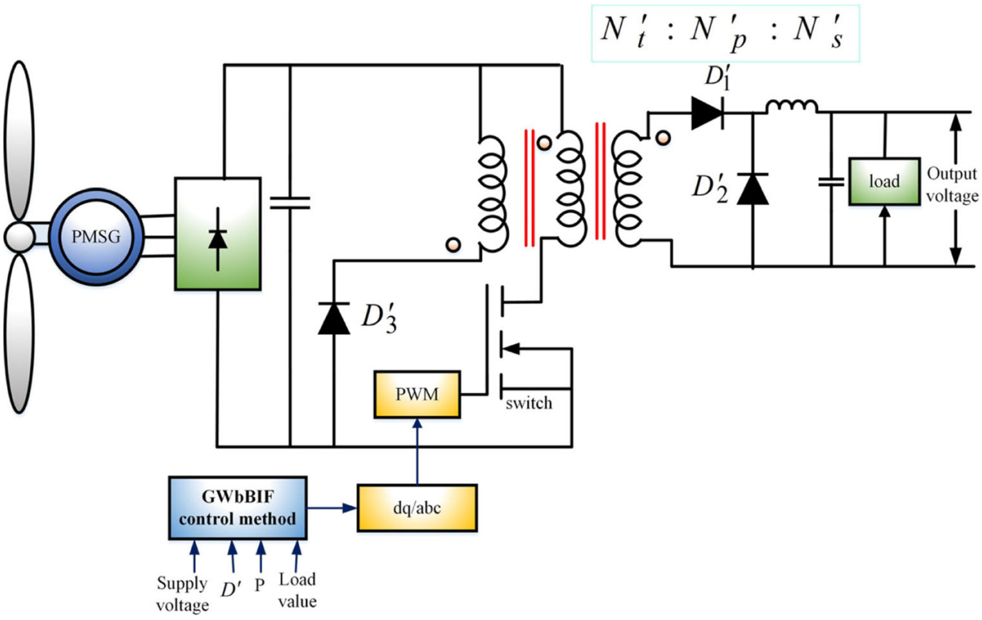

Fig. 3 Proposed GWbBIF control method in wind system

places nearby the finest gain can be attained with respect to the present location of gain by regulating the vectors and values of $\overrightarrow{B}$ and $\overrightarrow{D}$. The GWbBIF method has been identifying the location of error and enclosed that error for minimizing.

Initially, the error estimation is directed by the gain ε then rarely φ and κ also enclosed in error estimation. The gain parameter ε is assumed as the finest gain solution also the gain parameter φ and κ have the finest knowledge about the probable position of error. Therefore, the finest gain parameter for the controller has been achieved and includes γ renewing the gain values based on the location of the finest gain agent. Here, boosting algorithm has been applied for error prediction and required gain value estimation. The weak gains are integrated to form a strong gain that will forecast an additional accurate error output. Initial weights of the overall error are expressed as $M : M_1, M_2. \ldots .M_n = 1/n$. The position of error has been estimated based on the gain parameter value using Eq. (6).

$$e^j = \frac{\sum_{k=1}^{n} M_k I\left(\overrightarrow{Y}^j\left(\overline{Y}_q(s) \neq Z_k\right)\right.}{\sum_{k=1}^{n} M_k} \tag{6}$$

Where the number of weights is denoted as n, k is the initialization value, I is the learning parameter and $c$is the constant vector. For a weak gain $\overrightarrow{Y}$ and $\overline{Y}_q(s) : n \times c, Z : n$ with test weighs $M : n \times 1$ at that condition of expression in Eq. (6) and $Z$is the training sequence. The coefficient of $\overrightarrow{Y}$ is analyzed for the expression in Eq. (7),

$$\sigma^j = \log\left(\frac{1-e^j}{e^j}\right) + \log(k-1) \tag{7}$$

Furthermore, the weights are increased for further error prediction if the estimation is wrong by Eq. (8),

$$M_k = M_k * f^{I\left(\overrightarrow{Y}^j\left(\overline{Y}_q(s) \neq Z_k\right)\right.} \text{ for } M_k \text{ belongs to } M \tag{8}$$

The weights of the error data should be normalized using Eq. (9),

$$M = M - Aveage(M) \tag{9}$$

Output of the system is completed via weighted elective charged the period of highest division that can be predicted expressed in Eq. (10),

$$Z_k = \max_g \left(\sum_{k=1}^{n} \sigma^j I\left(\overrightarrow{Y}^j\left(\overline{Y}_q(s) = g\right)\right.\right. \tag{10}$$

Based on the predicted error value, the gain values are optimized. If the error is high, then the gain value will be more. The fitness function to optimize the gain values for switching pulses of PWM control circuit is estimated by Eq. (11),

$$\overrightarrow{Y}(s+1) = \frac{\overrightarrow{Y}_1 + \overrightarrow{Y}_2 + \overrightarrow{Y}}{3} \tag{11}$$

Where the fitness values of $\overrightarrow{Y}_1$, $\overrightarrow{Y}_2$, and $\overrightarrow{Y}$ are estimated by the Eqs. (12), (13) and (14),

$$\overrightarrow{Y}_1 = \overrightarrow{Y}_\varepsilon - \overrightarrow{B}_1.\left(\overrightarrow{E}_\varepsilon\right) \tag{12}$$

$$\overrightarrow{Y}_2 = \overrightarrow{Y}_\varphi - \overrightarrow{B}_2.\left(\overrightarrow{E}_\varphi\right) \tag{13}$$

$$\overrightarrow{Y}_3 = \overrightarrow{Y}_\kappa - \overrightarrow{B}_3.\left(\overrightarrow{E}_\kappa\right) \tag{14}$$

The estimated values are provided to the Eq. (11) for optimizing the gain parameter. Furthermore, the vector coefficient of each duty cycle of forward converter is estimated by the Eqs. (15), (16) and (17),

$$\vec{E}_{\varepsilon} = \left|\vec{D}_1 . \vec{Y}_{\varepsilon} - \vec{Y}\right| \tag{15}$$

$$\vec{E}_{\varphi} = \left|\vec{D}_2 . \vec{Y}_{\varphi} - \vec{Y}\right| \tag{16}$$

$$\vec{E}_{\kappa} = \left|\vec{D}_3 . \vec{Y}_{\kappa} - \vec{Y}\right| \tag{17}$$

- *Exploitation Stage*

The gain parameter values are completed the search by reducing the error while it stops moving. From the mathematical optimization approach of error, the value of $\vec{b}$ is decreased also the variation of $\vec{B}$ decreased by the value $\vec{b}$. Consequently, the coefficient vector $\vec{B}$ is an arbitrary value belongs to –b to b, here b is diminished from two to zero than the sequence of iterations. While the arbitrary value of $\vec{B}$ is considered as [−1, 1], then the following location of a gain point can be placed in any location among its present value in addition to the location of the error. Thus, the GWbBIF method permits its duty cycle to update its location depends upon the gain values of ε, φ and κ also to the error.

- *Exploration stage (Power loss)*

The power loss of the transformer has been optimized by the fitness of GWbBIF exploration stage, which is evaluated by Eq. (18).

$$\vec{Y}(s+1) = P_{\varepsilon}\vec{Y}_1 + P_{\varphi}\vec{Y}_2 + P_{\kappa}\vec{Y} \tag{18}$$

Where $P_{\varepsilon} + P_{\varphi} + P_{\kappa} = 1$ besides, P_{ε}, P_{φ} and P_{κ} are the overall weights of the transformer. Hence, the proposed GWbBIF method regulated the PWM of the forward converter by varying the switching pulses along with the error

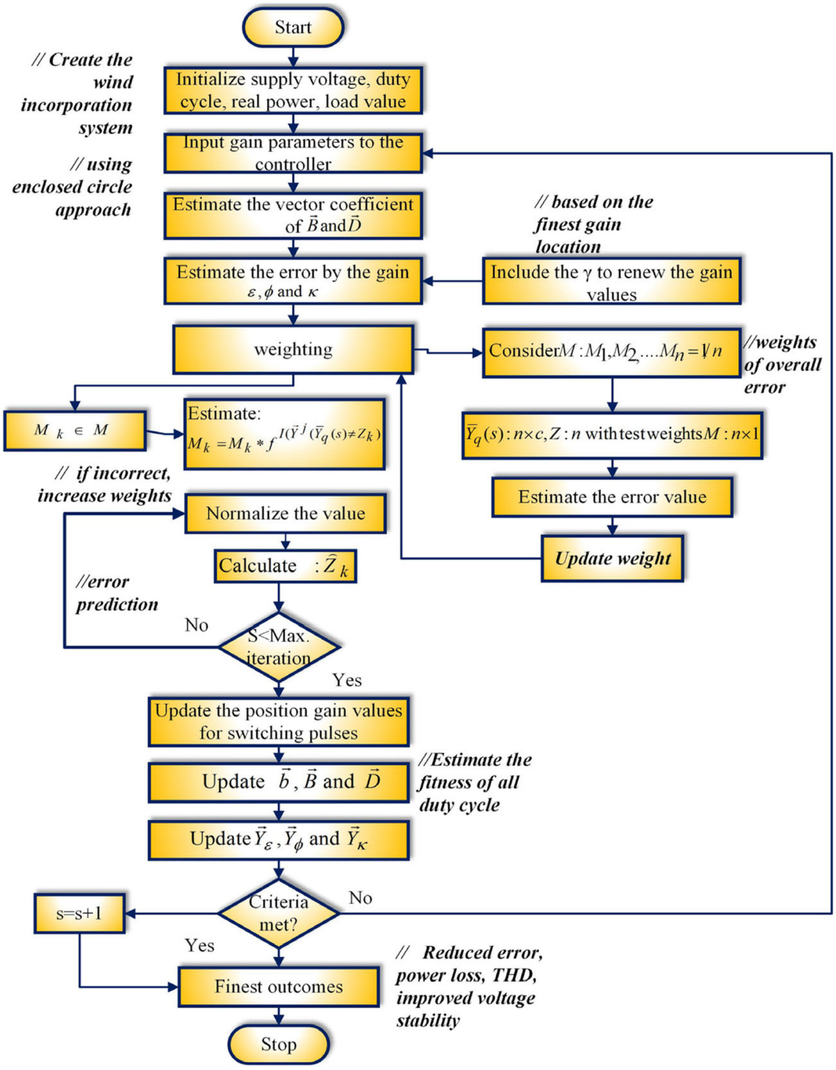

Fig. 4 Overall workflow of Proposed GWbBIF control method in forward converter with wind system

reduction using the optimized gain value. In addition, the power loss of the transformer is minimized. This process is stops when the finest outcome has obtained; otherwise, it repeated until the criteria of the system meet. The flowchart and algorithm of the proposed GWbBIF method in wind system are detailed in Fig. 4 and algorithm 1.

Algorithm 1: GWbBIF method for forward converter

```
Start
{
Create the wind incorporation system
Initialize the input parameters: Supply voltage, duty cycle, real power, load value
Input gain parameters to the controller. // using enclosed circle approach
Estimate the vector coefficient of $\vec{B}$ and $\vec{D}$.
    Location of gain renew based on the location of error values
    Estimate the error by the gain ( $\varepsilon$ , $\phi$ and $\kappa$ )
    Include the $\gamma$ to renew the gain values        // based on the finest gain location
weighting ()
    For all current error
    Consider $M: M_1, M_2 .... M_n = 1/n$        //weights of overall error
    For j in $[1, M]$        // $M$ weak gains
    For a weak gain $\vec{Y}$
    $\overline{Y}_q(s): n \times c, Z: n$ with test weights $M: n \times 1$
    $e^j = \frac{\sum_{k=1}^{n} M_k I(\vec{Y}^j(\overline{Y}_q(s) \neq Z_k)}{\sum_{k=1}^{n} W_k}$
    $\sigma^j = \log\left(\frac{1-e^j}{e^j}\right) + \log(k-1)$        // coefficient of $\vec{Y}$
    End for
    End for
    Update the weights
    For $M_k$ belongs to $M$
    $M_k = M_k * f^{I(\vec{Y}^j(\overline{Y}_q(s) \neq Z_k)}$        // if incorrect, increase weights
    End for
    End for
Normalize the data()
    $M = M - Aveage(M)$        // normalize weights
    $\hat{Z}_k = \max_g \left( \sum_{k=1}^{n} \sigma^j I(\vec{Y}^j(\overline{Y}_q(s) = g \right)$        //error prediction
while (s < Ma. iterations)
    for each duty cycle value
        Update the position gain values for switching pulses by eqn. (11)
    end for
    Update $\vec{b}$ , $\vec{B}$ , and $\vec{D}$
    Estimate the fitness of all duty cycle in eqn. (12) to (14)
    Update $\vec{Y}_\varepsilon$ , $\vec{Y}_\phi$ , and $\vec{Y}_\kappa$
    s=s+1
end while
return $\vec{Y}_\varepsilon$
Finest outcomes        //Reduced error, power loss, THD, improved voltage stability
}
Stop
```

Result and Discussion

The planned scheme is broadly elaborated using the MATLAB framework, and the efficiency measure of the designed model is compared with other conventional converter models in terms of Harmonic distortion, Error, Power stability, Voltage current, Grid current, Load current, Complexity, and Time. The parameters used for the proposed Simulink is represented in Table 1.

Case Study

Consider the input supply voltage is 36 V, real power from the wind is 500 W, the duty cycle value is 0.3, and the load value is 1 kΩ. The nominal value of voltage is 40 V. Initially, the gain parameter for the controller is initialized as ε=1.3 dB, φ=2.3 dB, and κ=10.9 dB. The rest of the gain is γ =0. The parameters are enclosed using Eq. (2), so $\overrightarrow{B}$ and $\overrightarrow{D}$ value is estimated from the Eqs. (4) and (5). The $\overrightarrow{B}$ and $\overrightarrow{D}$ of vector coefficient is estimated by Eq. (4),

$$\overrightarrow{B} = 2\overrightarrow{b}.\overrightarrow{t}_1 - \overrightarrow{b} = 2 \times 2 \times 0.814 - 2 = 1.256$$
$$\overrightarrow{D} = 2.\overrightarrow{t}_2 = 2 \times 0.9058 = 1.8116$$

The arbitrary vectors are assumed as $\overrightarrow{t}_1 = 0.814$ and $\overrightarrow{t}_2 = 0.9058$ also $\overrightarrow{b} = 2$. Then the value $\overrightarrow{E}$ is calculated as,

$$\overrightarrow{E} = |1.8116 \times 4 - 0.3| = 6.9$$

where the location vector of error is considered as $\overline{Y}_q(s) = 4$, and the location vector of duty cycle is assumed as $\overrightarrow{Y} = 0.3$. The initial iteration is taken as s=0; then the encircling approach is evaluated by Eq. (3).

$$\overrightarrow{Y}(1) = 4 - 1.256 \times 6.9 = -4.7$$

Table 1 The parameters used for the proposed Simulink

Parameter	Values
Input voltage	36 V
Output voltage	48 V
Switching frequency	20 kHz
Utmost output power	500 W
Transformer turn ratio	1:4
Output filter capacitor	12.5 µF
Output filter inductor	16 mH
Duty cycle[a]	0.3

[a] It is defined as the fraction of individual time that the system is ON

Initial weights of the overall error are assumed as $M : 0.1, 0.1.....0.1 = 1/4$ in the boosting algorithm. The position of error has been estimated by Eq. (6) is,

$$e^j = \frac{\sum_{k=1}^{4} M_k I\left(0.3^1 (4 \neq Z_k)\right.}{\sum_{k=1}^{4} M_k} = 0.3$$

For a weak gain $\overrightarrow{Y}$, the value of I is considered as 1. The coefficient of $\overrightarrow{Y}$ is analyzed in Eq. (7) as,

$$\sigma^j = \log\left(\frac{1-0.3}{0.3}\right) + \log(4-1) = 1$$

Consequently, updated the weight along with the obtained error values using Eq. (8) as,

$$M_k = 0.4 * f^{1\left(0.3(4 \neq Z_k)\right.} = 0.4 * 2^{0.3} = 0.49$$

For M_k belongs to M, normalized the weight by Eq. (9) and obtained as $M = 0.245$. Then the error is predicted using Eq. (10) as,

$$Z_k = \max_{g=1}\left(\sum_{k=1}^{4} 1 \times 1(0.3)(4)\right) = 4.8$$

Based on the predicted error value is high; thus, the gain values are optimized. Then, the vector coefficient of each duty cycle of forward converter is estimated by the Eqs. (15), (16) and (17) also obtained as,

$$\overrightarrow{E}_\varepsilon = |1.82 \times 1.2. - 0.3| = 1.884$$
$$\overrightarrow{E}_\varphi = |1.82 \times .2.6 - 0.3| = 4.432$$
$$\overrightarrow{E}_\kappa = |1.82. \times 10.9 - 0.3| = 19.54$$

The values of $\overrightarrow{Y}_1$, $\overrightarrow{Y}_2$, and $\overrightarrow{Y}$ are estimated by the Eqs. (12), (13) and (14) and obtained as,

$$\overrightarrow{Y}_1 = 1.3 - 1.256.(1.884) = -2.36$$
$$\overrightarrow{Y}_2 = 2.3 - 1.256.(4.432) = -5.56$$
$$\overrightarrow{Y}_3 = 10.9 - 1.256.(19.54) = -24.6$$

The fitness function to optimize the gain values for switching pulses of PWM control circuit is given by Eq. (11),

$$\overrightarrow{Y}(s+1) = \frac{-2.36 - 5.56 - 24.6}{3} = |-21.6| = 21.6$$

GWbBIF method allows the duty cycle to update its current 21.6 value of location to PWM pulses along with the gain values of ε, φ and κ as well as an error value.

- *Exploration stage (Power loss)*

The transformer power loss is optimized by the fitness of GWbBIF exploration stage by Eq. (18),

$$\overrightarrow{Y}(s+1) = 0.34 \times (-2.36) + 0.35 \times (-5.56) + 0.31 \times (-24.6) = -10.37W$$

Then assume the overall weights of the transformer value of P_ε =0.34, P_φ =0.35 and P_κ=0.31, $P_\varepsilon + P_\varphi + P_\kappa = 1$. Thus, the gain parameter value is optimized along with the duty cycle value for PWM conversion. Also, the transformer power loss is significantly optimized.

Performance Analysis

The performance analysis of projected method in forward converter incorporated with the wind system is carried out in MATLAB. The graphical representation of load current is illustrated in Fig. 5. Here, the current values are changed among negative 120A as well as positive 120A at the time of 0 towards 0.1 s.

The wind current from the model is illustrated in Fig. 6. Here, the current values of wind in the projected model are changed from 50A to -50A. However, due to the varying conditions of the system, the sinusoidal values are fall changes.

The wind voltage from the model is illustrated in Fig. 7. Moreover, the voltage of wind is changed from 600 V to -500 V. However, this voltage from the wind is within the boundary of 500 V to -500 V during the time interval of 0 towards 0.1 s.

The torque characteristic of wind turbine is illustrated in Fig. 8. The typical generator torque depends upon the wind speed and power of the generator. Initially, the oscillation is happened till the 0.01 s because of varying wind speed; after that, due to the normalized speed the torque value tends stable.

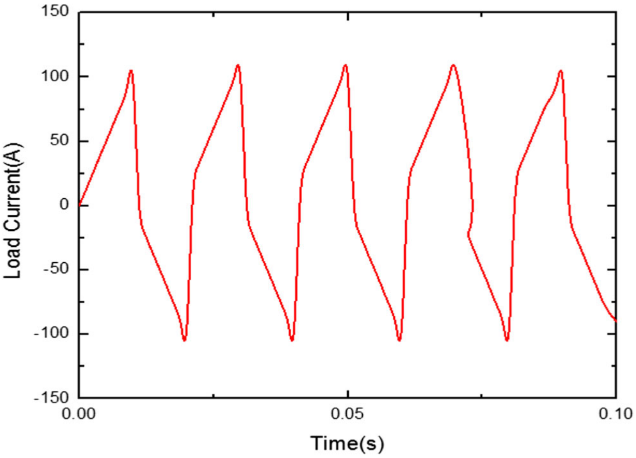

Fig. 5 Load current with respect to the time period

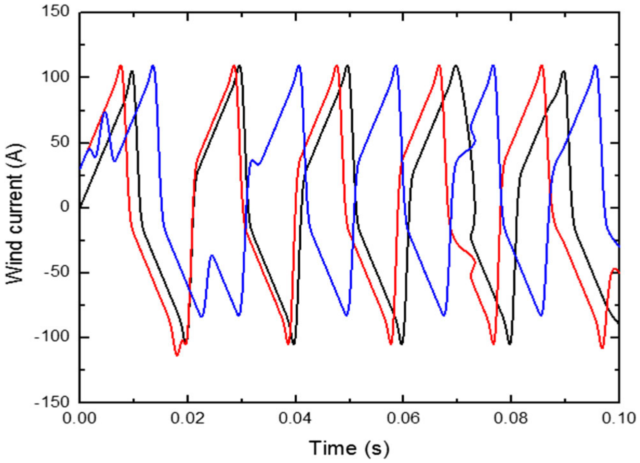

Fig. 6 Wind current from the model

The Forward converter response during duty cycle 0.3 is represented in Fig. 9a-c. The input voltage of the system is provided as 38 V is shown in Fig. 9a. Here, the voltage starts 30 V as initially, then maintained constant as 25 V till 0.035 s.

After that, the voltage is maintained constant as 38 V. Similarly, the output voltage of the forward converter under the finest duty cycle of 0.3, the voltage value varies from zero to 48 V in 0.015 s that is illustrated in Fig. 9b. Consequently, the load current value is measured, which is varied from 0 towards 0.9A in 0.01 s and maintained the level constant is demonstrated in Fig. 9c. Moreover, the voltage gain rate of projected control method and duty ratio in forward converter is represented in Fig. 10. While increased the duty cycle ratio as 0.3, then the gain parameters ε, φ and κ is increased as the turn ratio of 1.3, 2.3 and 10.9.

Consequently, the error rate obtained from the proposed system is estimated based on the desired and processed value, which is illustrated in Fig. 11. The observation shows that the error percentage is varied as 0.03% with the 100 number of iteration.

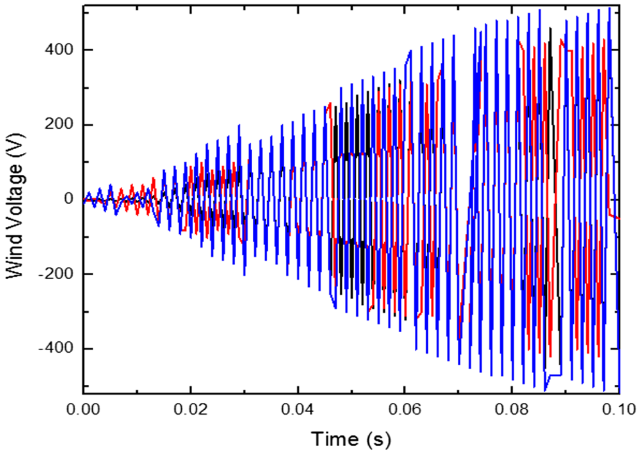

Fig. 7 Wind voltage from the model

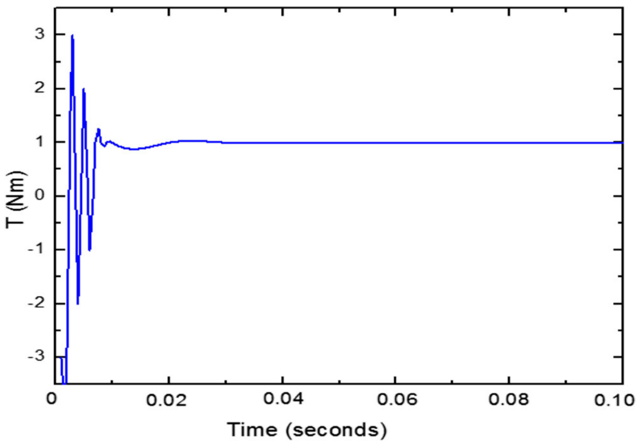

Fig. 8 Torque characteristics of wind turbine

The representation of the obtained THD rate is illustrated in Fig. 12. The THD of the system has been calculated for the proposed system that is obtained as 1.02% at 0.8A. The obtained THD value is satisfied within the limit of IEEE standard 519–2014.

The stability of the Proposed GWbBIF model in the wind incorporation system is validated, which is shown in Fig. 13. The achieved gain margin is 6.24 dB, and the phase margin is 13.6 deg. Thus, observation illustrates that gain margin and phase margin are increased in the stability analysis of the developed model. Due to the gain and phase margin increase, the system tends to stable.

For validating the effectiveness of proposed methods, it is compared with the conventional methods such as Artificial Bee Colony (ABC) [6], Fitness Oriented based Rider optimization algorithm (FO-ROA) [23], Nearest Level Modulation based Selective Harmonic Elimination (NLM-SHE) [27] and Genetic algorithm with Adaptive Neuro-fuzzy inference scheme (GA-ANFIS) method [4]. Consequently, the graphical analysis of the convergence curve of power loss changes the iteration count commencing 0 to 100 and comparison with existing methods is illustrated in Fig. 14. Correlating to forward converter, the iteration count is applied at the 40th iteration. The analysis observed that the objective power loss is diminished as 0.24 MW, while compared with the existing methods; the attained power loss is very less.

Furthermore, the performance analysis of the overall system in forward converter in terms of error, power loss (MW), THD (%), error, and computational time (s) and it is compared with the conventional methods like ABC [6], FO-ROA [23], NLM-SHE [27] and GA-ANFIS method [4]. The THD and error percentage are compared with the existing methods are shown in Fig. 15. The comparison shows that the proposed system has attained less THD over the other methods because the proposed system THD rate is 1.02%, but conventional ABC, FO-ROA, NLM-SHE and GA-ANFIS methods have obtained 3.21%, 17.77%, 2.27% and 3.069%.

The estimation of error in Proposed GWbBIF expressed the enhancement of projected model because the proposed method has attained 0.02% of error over the conventional methods

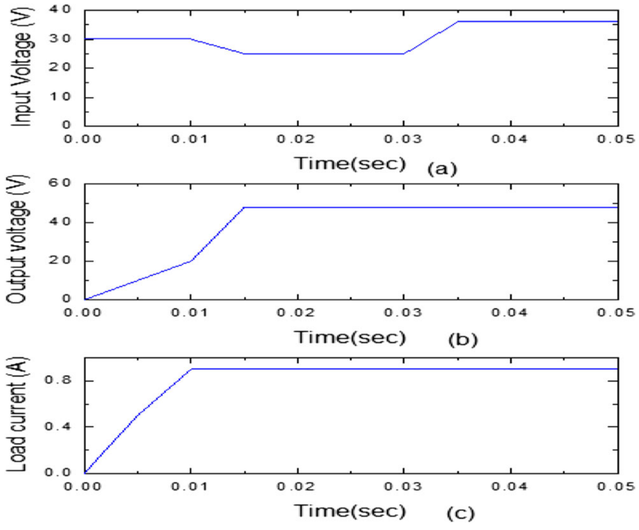

Fig. 9 **a-c** Forward converter response during duty cycle 0.3

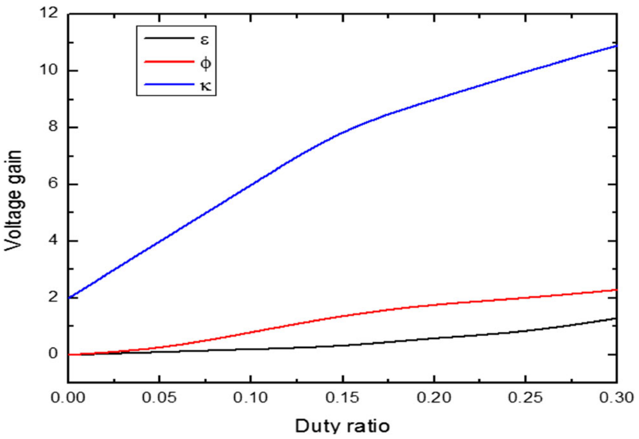

Fig. 10 Voltage gain rate of projected control method and duty ratio in forward converter

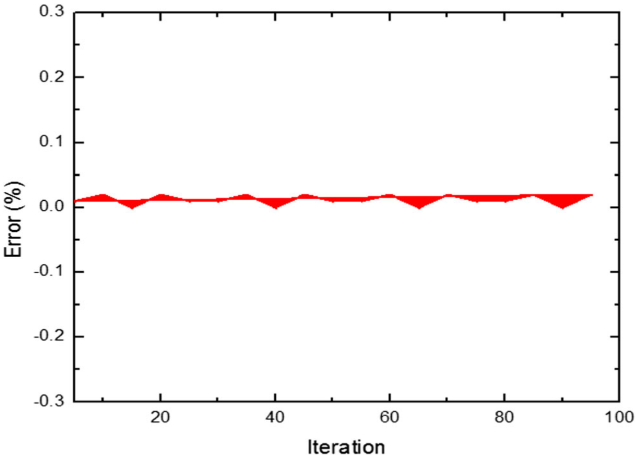

Fig. 11 Error percentage over the iteration

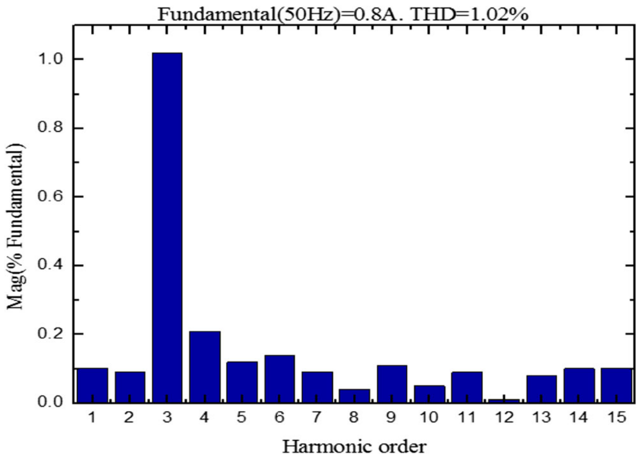

Fig. 12 THD rate of proposed system

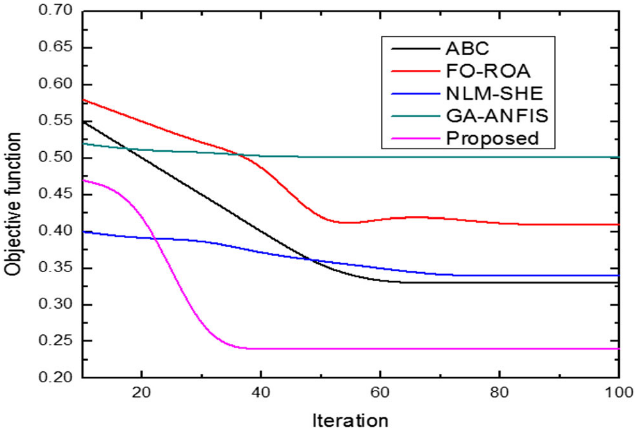

Fig. 14 Power loss objective function over iteration

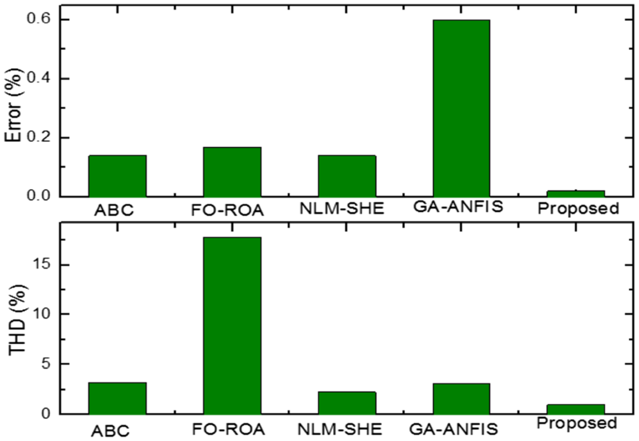

Fig. 15 Comparison of THD and error percentage over existing methods

ABC [6], FO-ROA [23], NLM-SHE [27] and GA-ANFIS [4] were achieved 0.14%, 0.17%, 0.14% and 0.6% respectively.

Also, the power loss calculated from this research is compared with the conventional techniques are demonstrated in Fig. 16. While compared with the existing ABC [6], FO-ROA [23], NLM-SHE [27] and GA-ANFIS [4] methods, the proposed system has attained very less power loss as 0.24 MW.

Furthermore, the total computation time for the execution is analysed, and the achieved time value is contrasted with the existing methods are represented in Fig. 17. Here, the illustration shows that the proposed method has taken very less time than other traditional methods. The overall comparison of the proposed GWbBIF method over exiting methods is detailed in Table 2.

Thus, the tabulation detailed that the THD, power loss reduction, error and computational time value of the proposed GWbBIF method exploited supreme improvement in the projected framework while contrasted to the conventional methods like ABC [6], FO-ROA [23], NLM-SHE [27] and GA-ANFIS method [4]. Also, the stability of the system is improved over other methods and articulated as a simple driving circuit. Thus, the entire analysis clearly illustrates the projected method has obtained reduced power loss and THD value which is optimal to the wind coordination with the forward convertor in the grid system. Consequently, this proves that the developed system is highly effective for high power applications.

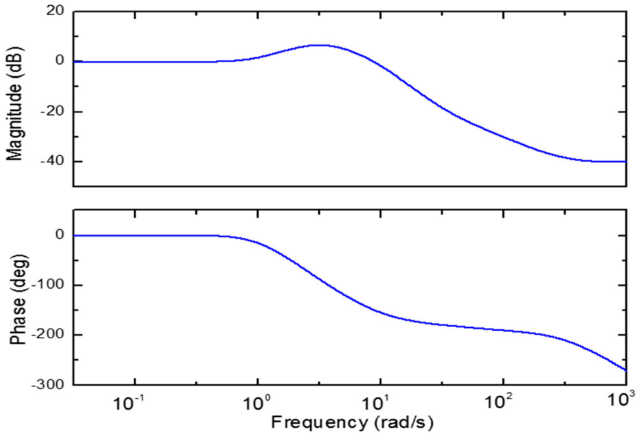

Fig. 13 Stability analysis of the proposed system

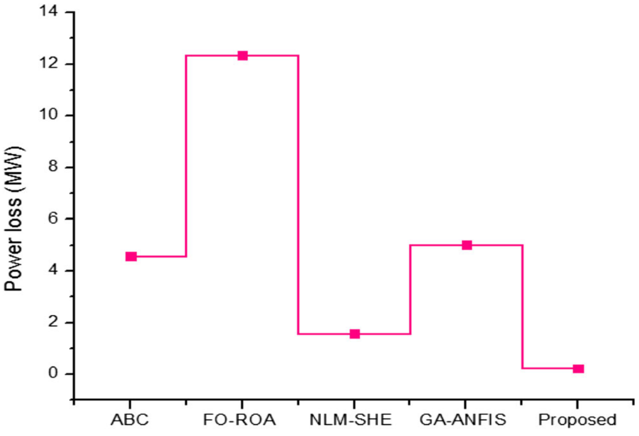

Fig. 16 Comparison of power loss over existing methods

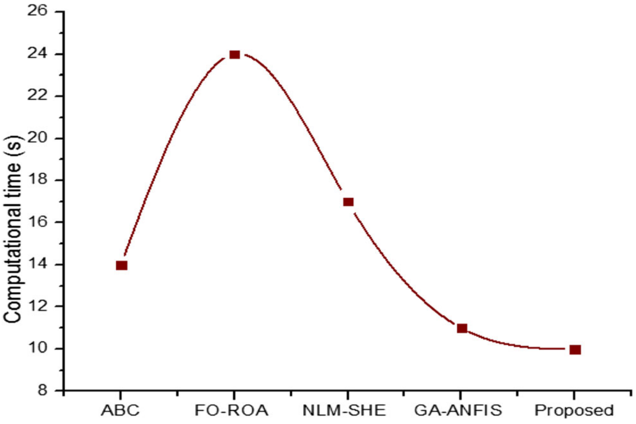

Fig. 17 Comparison of computational time over existing methods

Discussion

The State of the art methods over proposed model is discussed in Table 3. In this tabulation, the merits and disadvantages of proposed and existing methods are discussed clearly. In previous, some commonly used methods like Power Topology [9], Trapezoidal Current Frame [14], Hierarchical Frame (Zhang et al. [33], ABC [6], FO-ROA [23], NLM-SHE [27] and GA-ANFIS [4] methods. These methods have certain advantages in the process of power loss reduction in forward converter transformer. However, this method cannot attain the finest result in advanced power network applications. The conventional Power Topology [9] and Power Tracking Model [3] have attained high gain value for the forward converter, yet due to the variation of load the error rate will high and this will leads to increase the cost of the process. Also, Converter Analysis [10] has attained accurate estimation, but the computational cost affects the usage in real-time applications.

The proposed GWbBIF has attained less error, THD computational time, and power loss over other conventional methods. Moreover, the proposed GWbBIF method has no complexity in the control of forward converter transformer. Thus, it is mainly applicable in the wind energy system and achieved very less error of 0.24 MW. Nevertheless, the con-

Table 2 Overall comparison of proposed over conventional methods

Method	ABC [6]	FO-ROA [23]	NLM-SHE [27]	GA-ANFIS [4]	Proposed GWbBIF
THD (%)	3.21	17.77	2.27	3.169	1.02
Power loss (MW[a])	4.5804	12.35	1.57	5.02	0.24
Operating power	Low power	Medium power	Low power	High power	High power
Driving circuit	Complex	Less complex	Complex	Highly complex	Simple
Error	0.14	0.17	0.14	0.6	0.02
Stability	unstable	Slightly stable	Difficult to stable	Unstable	Stable
Time (s)	14	24	17	11	10

[a] MW referred to as MegaWatt

Table 3 State of the art methods over proposed model

Author	Methods[a]	Merits	Limitation
Zhang et al. [33]	Hierarchical Frame	Finest stability	Fail to reduce more power loss
Gruner et al. [9]	Power Topology	Optimized the gain and input current effectively	High error due to the variation of load
Başoğlu [3]	Power Tracing Model	High gain has achieved	Cost is high
Habib et al. [10]	Converter Analysis	Accurate measurement is possible	Computation cost is high
Li et al. [14]	Trapezoidal Current Frame	Reduced power loss significantly	Computational time is high
[6]	ABC	High flexibility to the complicated problems	Premature convergence
[23]	FO-ROA	Finest convergence rate	Complex and computationally burden
[27]	NLM-SHE	Reduce the THD value	It rapidly executes but not support all the modulations of control in converters
Durgadevi and Umamaheswari [4]	GA-ANFIS	High learning capacity and error rate is more	Complexity for the nonlinear process
Proposed	GWbBIF	Less error, computational time is low, less THD, low power loss and no complexity to design	Local search of control parameter ability should be improved

[a] State of the art methods is compared with proposed method

ventional methods have not improved the reliability of the converter and transformer. Yet, the proposed method has improved the stability and reliability of the forward converter transformer. The THD values obtained from the different existing methods are within the limit of IEEE standard. However, the projected method has attained 1.02% of THD, which is very less than the conventional methods. Also, the GWbBIF has significant rapid convergence and improved the stability performance of the system. Hence, the proposed GWbBIF method can solve real-time issues. The discussion shows that the projected GWbBIF method has attained superior performance in terms of less complexity, computational time, THD, power loss, and error over the conventional state of the art methods.

Conclusion

The main objective of this research is to reduce the power loss in the transformer while the wind is coordinated with the forward converter. Therefore, a novel GWbBIF method has been developed for the forward converter coordination system. The power loss has been reduced up to 0.24 MW, and the error is 0.02%. Also, the obtained THD value is 1.02%, and computational time is 10s. The projected method has attained less THD, minimized power loss, and reduced error percentage over the conventional methods. Thus the overall performance analysis demonstrates that the proposed GWbBIF method is more suitable in the forward convertor coordination system. Consequently, the computational time is also reduced significantly. In future, a new hybrid machine learning algorithm will develop for improving the controller parameter ability.

Declarations

Disclosure of Potential Conflict of Interest The authors declare that they have no potential conflict of interest.

Statement of Human and Animal Rights None

Ethical Approval. All applicable institutional and/or national guidelines for the care and use of animals were followed.

Informed Consent. For this type of study formal consent is not required.

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