International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Power Losses Reduction of Stacked Multicell Converter Fed Wind Energy Conversion System (WECS) Using Hybrid Methodology

Subhashini B.N[1], Dr. P Pramila[2]

[1]Assistant Professor, Electronics & Communication Dept., Vivekananda Institute of Technology
[2]Professor, Electrical & Electronics Dept., Bangalore Institute of Technology

Abstract

This paper proposes a hybrid method for reduction of power losses of multicell converter in wind energy conversion system (WECS). The proposed methodology is the Artificial Intelligence (AI) based phase disposition pulse width modulation (PD-PWM). The Artificial Intelligence (AI) is the Gradient Boosting Decision Tree algorithm (GBDT). Hence it is named as GBDT-PD-PWM. Gradient boosting is a machine learning system that creates a prediction model in the group of weak prediction models, often called decision trees. The multicell converter is employed as the grid side converter (GSC) of WECS to attenuate harmonics created by nonlinear load. For stacked multicell converters (SMCs), a method of capacitor voltage balance based on PD-PWM approach is proposed. This technique is also known as "optimal transition voltage balancing system," which employs optimal switching transitions. This proposed method is the further development of the optimal state voltage balancing method (OSVB), where the number of switching is not optimized. The performance of the proposed technique is implemented in the MATLAB platform and compared with the existing methods. The performance of the proposed system is evaluated under the fault condition. The power loss of the proposed method is less compared to the existing method, which is revealed from the simulation outcome.

Keywords: Stacked multicell converter, Wind energy conversion system (WECS), Grid side converter (GSC), Reliability, Nonlinear load, Fault, Gradient Boosting Decision Tree Algorithm (GBDT), Phase Disposition Pulse Width Modulation (PD- PWM)

1. Introduction

Due to the world's fast rising energy demand and the upcoming depletion in global fossil fuel sources, energy sustainability will pose a significant issue in the coming years [1]. To fulfill the rising need for energy on a worldwide scale, more alternative green energy depends on the usage of renewable resources [2]. Currently, the majority of the renewable electricity produced worldwide comes from wind and solar energy [3]. As a result of the increasing the installed wind energy capacity, grid operators are establishing novel criteria [4]. New control strategies could be used to improve wind turbine generators' low voltage ride through (LVRT) capacity in order to keep them connected to the grid even in certain grid failure scenarios [5].

Due to their poor efficiency, two level voltage source converters are impractical as wind power conversion systems have reached 10MW in power capacity. Hence, we use multilevel converter technology [6]. Multicell series converters are made up of simple switching cells that have been serialized [7-8]. When an appropriate phase control approach is used, this architecture ensures that the various low voltage semiconductor devices connected in series are subjected to an equal amount of stress [9].

However, the multicellular structure necessitates the employment of floating capacitors, whose terminal voltages should be managed and kept within predetermined ranges [10].
Voltage source converters is the most often used power converter structure for wind turbine systems. In this research a stacked multicell converter is used. The current flowing into the generator rotor or stator in a wind turbine system should be managed to control electromagnetic torque to improve the extracted power from wind turbine and balance energy in case of dynamics.

2. Recent Research Works: A Brief Revie

Various works are existing on literature on power loss reduction and power quality improvement of wind turbine system. Some of them are discussed as follows:
M. Annoukoubi, *et al.* [11] have presented performance of WECS using typical two-level and three-level converter. Wind energy was directly converted into electricity by renewable WECS, which was often linked to the power grid using standard two-level converters.

R. Boopathi, *et al*. [12] have suggested an effort to utilize the greatest amount of power available from wind source, new perturb-and-observe (P&O)-fed maximum power point tracking (MPPT) to develop front-end single-ended primary-inductor converter.

M. Basic, *et al.* [13] have utilized a novel energy-efficient WECS control technique The WECS under consideration was intended for dc load supply and battery charging on stand-alone applications. A three-phase full bridge power converter charges the batteries. In ac side, the WECS has a self-excited induction generator (SEIG) linked to a wind turbine (WT).

B Sahoo, *et al.* [14] have created the current decomposition approach depends on unique instantaneous power theory for improving the power quality and reliability of dc-grid utilized in chicken farm.

3. Configuration of Multicell Converter Connected Wind Energy Conversion Systems (WECS)

Figure 1 depicts the proposed WECS configuration. WECS multicellular converter is employed as a grid side converter. In this paper, a hybrid GBDT-PD-PWM is presented for system fault tolerance. The proposed approach is used to maintain active power and diminish mechanical vibrations while injecting electric power into the grid.

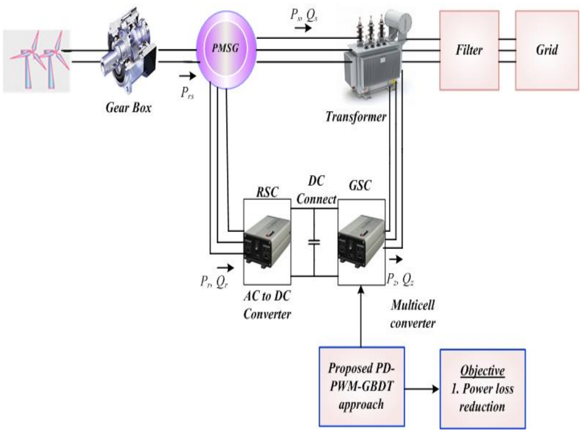

Fig 1: Configuration of the proposed WECS

3.1. Aerodynamic Model of Wind Turbine

The available mechanic power at turbine shaft is stated as below:

$$p_M = \frac{1}{2}\rho\pi r_T^2 V_W{}^3 c_p(\lambda) \qquad (1)$$

Here, r_T^2 implies radius of blade of WT, ρ refers density of air, V_W refers wind speed, c_p implies coefficient of power and λ denotes TSR that is given by

$$\lambda = \frac{\Omega_H r_T}{V_W} \qquad (2)$$

Here Ω_H (rad/s) refers high speed shaft (HSS), $\Omega_H = \Omega_I$ and I refer transmission ratio. The mechanical torque delivered by wind turbine to the rotor shaft is given by

$$\Gamma_M = \frac{1}{2}\rho r_T^2 V_W{}^3 c_Q(\lambda) \qquad (3)$$

Here c_Q refers torque coefficient that is given by

$$c_Q(\lambda) = \frac{c_p(\lambda)}{\lambda} \qquad (4)$$

c_p, c_Q, λ_{opt} refers to designed parameters that are generally delivered by Wind Turbine manufacturer.

The following equation is expressed as Wind Turbine's output power, where rated wind speed is denoted as Sr, cut-out wind speed is expressed as Sco and cut-in wind speed is denoted as S_{Ci}.

$$P_{WT} = \begin{cases} 0 & S < S_{Ci} \text{ or } S > S_{CO} \\ S^3\left(\frac{P_r}{S_r^3 - S_{Ci}^3}\right) - P_r\left(\frac{S_{Ci}^3}{S_r^3 - S_{Ci}^3}\right) & S_{Ci} \le S \le S_r \\ P_r & S_r \le S \le S_{CO} \end{cases}$$

$$\begin{bmatrix} v_{c1} \\ v_{c2} \\ I_F \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{-r_F}{l_F} \end{bmatrix} \begin{bmatrix} v_{c1} \\ v_{c2} \\ I_F \end{bmatrix} + \begin{bmatrix} \frac{-(I_l - I_G)}{c} & \frac{(I_l - I_G)}{c} & 0 \\ 0 & \frac{-(I_l - I_G)}{c} & \frac{(I_l - I_G)}{c} \\ \frac{v_{c1}}{l_F} & \frac{v_{c2} - v_{c1}}{l_F} & \frac{v_{DC} - v_{c2}}{l_F} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{-v_{DC}}{2l_F} - \frac{v_g}{l_F} \end{bmatrix} \qquad (5)$$

The switchesSn1, Sn2 are open and switches Sd1, Sd2 are closed and proposed power converter works as a multicellular converter.

4. Proposed GBDT-PD-PWM Based Power Loss Reduction of Multicell Converter

The GBDT-PD-PWM approach is proposed for reduction of power losses of multicell converter in WECS which is used as the GSC of WECS to reduce harmonics caused by nonlinear load. It restricts mechanical vibrations, and increases the multicellular converter's performance and reliability. A method of capacitor voltage balancing depends on the PD-PWM approach is given for stacked multicell converters (SMCs). Figure 2 depicts the proposed technique's control strategy. The following is a full description of the proposed method:

4.1. PD-PWM Based Voltage Balancing

The proposed voltage balancing technology is known as optimal transition voltage balance (OTVB). It is based on PD-PWM. The modulation specifies voltage level that must be given at GBDT's output.

$$I_{XS} = \frac{1}{2}\sum_{j=1}^{y-1} c_{XIZ}\,(v_{CXIZ} - v^{*}_{CXIZ})^{2} \qquad (6)$$

Here, X indicates phase a,b,c, and S refers to Switching State, v_{CXIZ} is the reference voltage. As a result, the cost function should be kept as low as possible. Differentiating (6), as illustrated below, can be used to carry out the minimizing method $\frac{d}{dt} I_{XSZ} = \frac{d}{dt}\frac{1}{2}\sum_{i=1}^{y-1} c_{XIZ}(v_{CXIZ} - V^{*}_{CXIZ})^{2} = \sum_{i=1}^{y-1}(\Delta v_{CXIZ} J_{CXIZ}) \le 0$

(7)

Where Δv_{CXIZ} refers voltage deviation of a FC , $\Delta v_{CXIZ} = v_{CXIZ} - \Delta v_{CXIZ}$ depends on selected redundant switching state and load current.

$$\min\left[\sum_{i=1}^{y-1}(\Delta v_{CXIZ}\, j_{CXIZ})\right] \qquad (8)$$

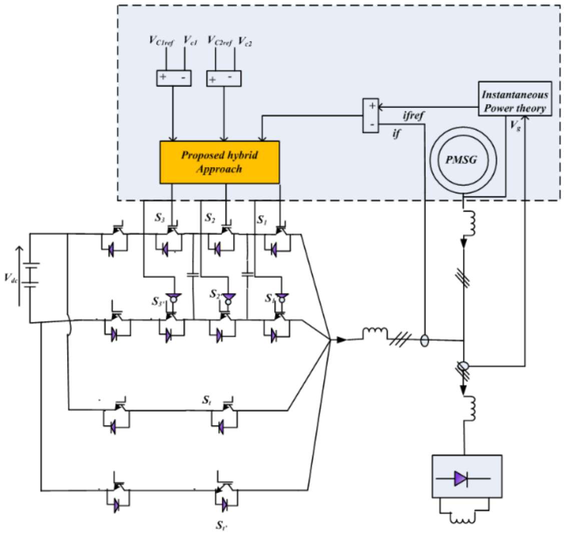

Fig2: Control approach of proposed technique

4.2. Prediction With GBDT Method

The GBDT is a boosting strategy that is modelled in a stage-wise fashion. It allows the optimization and offers the best data value. Its machine learning method is used in decision trees to estimate the ensemble weak parameter. It develops the stage-wise pattern, as do the other boosting methods, and generalises them by allowing optimization. The primary idea behind GBDT is to transform a collection of weak base classifiers into strong classifiers. Figure 3 depicts GBDT structure.

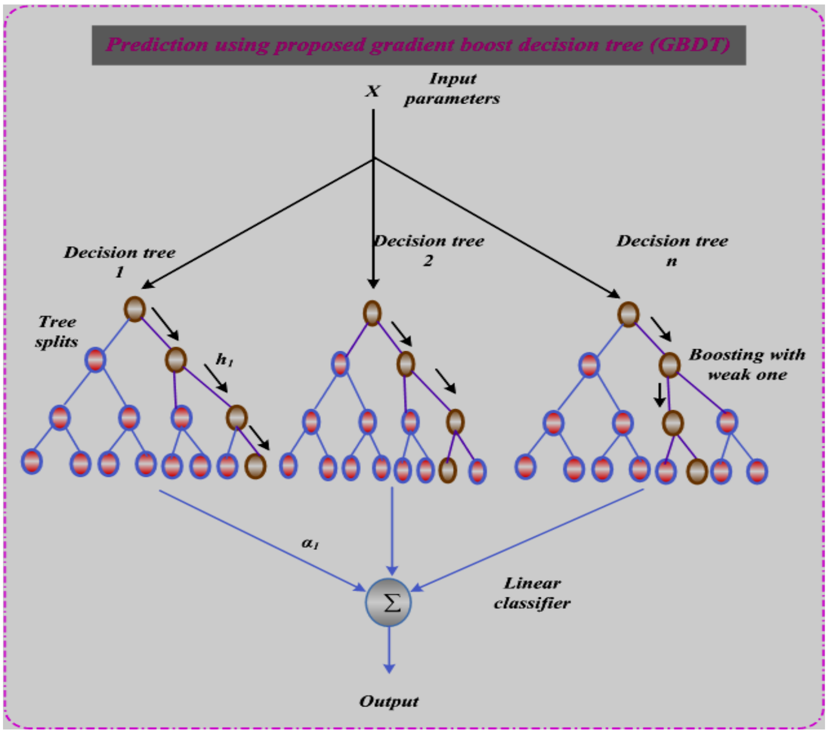

Fig 3: Structure of GBDT

The GBDT procedure is discussed in detail as follows :

Step 1: Initiation

Initiate the input vectors from the output of the AI approach. The initialized parameters are described by,

$$f_o(x) = \arg \min_{\kappa} \sum_{t=1}^{N} L(y_t, \kappa) \quad (9)$$

Step 2: Residual Calculation

Increase the iteration. Let C be iteration number C = 1, 2, 3… n, calculate the residual based on iteration, it is expressed by, $y_t = \left[\frac{\partial l(y_i, f(x_i))}{\partial f(x)} \right]_{f(x)=f_{m-1}(x)} \quad i = \{1,2,..n\}$ (10)

Step 3: Fit sample data

For every leaf node y_t, the better fit value of sample α_m is calculated.

$$a_m = \arg \min_{a,\kappa} \sum_{f=1}^{N} [y_i - \kappa h(x_i; a)]^2 \quad (11)$$

Using y_t as novel label of sample data set $h\lfloor(x_i;a_{,m})i=1,2,..n\rfloor$,a novel tree model takes leaf nodes $N_m(j=1,2..j)$.

Step 4: Find fitness function

It is considered by diminishing the loss function that may be planned as

$$\kappa_m = \arg\min_{a,\kappa} \sum_{f=1}^{N} [L(y_i, f_{m-1}(x) + \kappa h(x_i;a)] \quad (12)$$

Step 5: Updation

It is updated based on below equation,

$$f_m(x) = f_{m-1}(x) + \kappa_m h(x_i : a) \quad (13)$$

GBDT is trained depending on fitness function toget optimal output. By using the optimal control signal the proposed approach optimally predict the control signal.

5. Results and Discussion

The proposed hybrid PD-PWM-GBDT approach is utilized to decrease the loss of system and increase the power quality. The proposed method is simulated on MATLAB Simulink platform related to several existing methods such as Random Forest Algorithm (RFA), Convolution Neural Network (CNN) and Deep Convolution Neural Network (DCNN).

Comparison of grid active power is shown in Fig 4. Here the power is 0.3W at 0.002sec and increased to 1.9W at 0.004sec, decreased to 0.05sec at 0.8W and it remains stable for few sec. Then it suddenly decreases to 0W and increase to 2W at 0. 17sec.Then it drops to 0.9W.

Comparison of grid reactive power is shown in Fig 5. Grid power remains stable at 0W during 0 – 0. 01sec.Then suddenly decreases to -10W and increases to -0.9W during 0.05 to 0. 2sec.Reactivre grid power drops at 0. 16sec.Constant reactive grid power occurs at positive cycle.

Comparison of power loss is shown in Fig 6. It can be observed from Fig 7 that, by implementing the proposed method i.e by using Optimal transition voltage balancing (OTVB), the power loss incurred is less compared to the existing methods. Actually the power loss reduces by 5% with the proposed method compared to other existing methods.

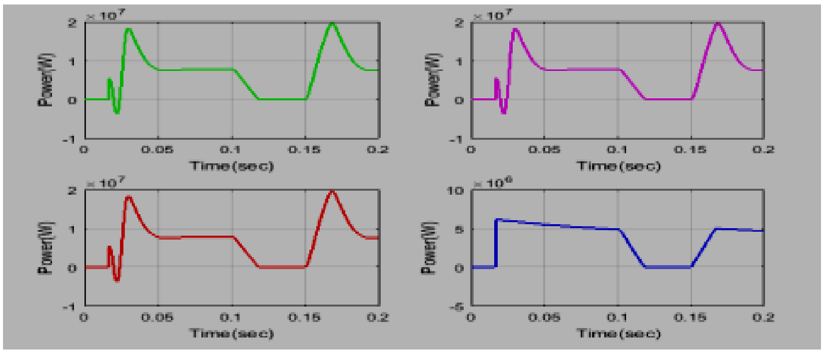

Fig 4: Comparison of grid active power

(a) RFA (b) CNN (c) DCN (d) Proposed

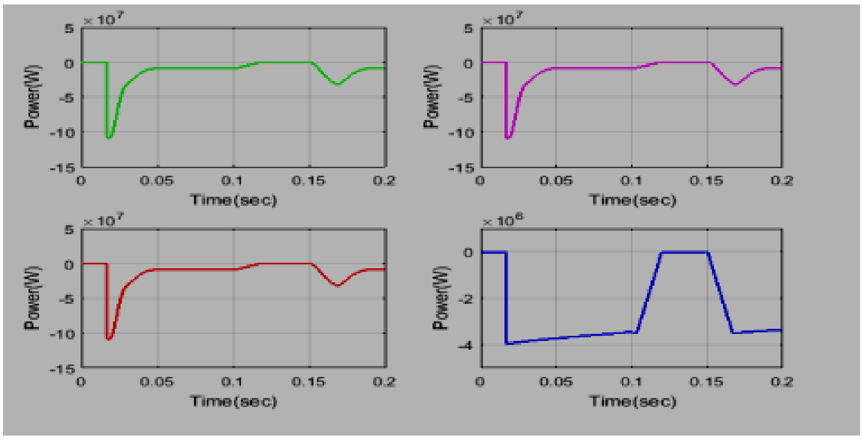

Fig 5: Comparison of grid reactive power

(a) RFA (b) CNN (c) DCNN (d) Proposed

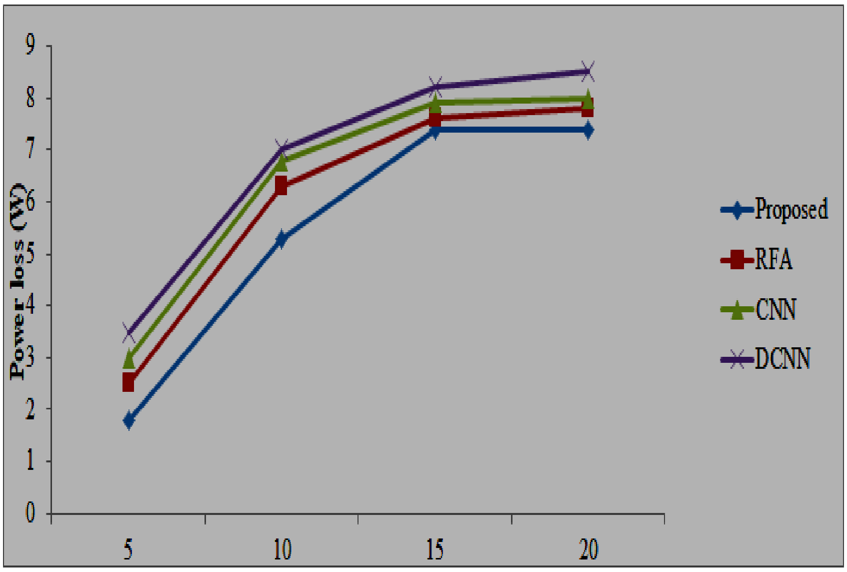

Fig 6: Comparison of power loss

Comparison table of power loss is as follows:

Method	Maximum power loss
RFA	7.5W
CNN	8W
DCNN	8.5W
Proposed method	7W

The overall power loss gets reduced by almost 5% with the proposed method compared to other methods.

6. Conclusion

A hybrid Artificial Intelligence (AI) based phase disposition pulse width modulation is proposed for reducing the power loss of the WECS in this paper. The proposed converter is the multi cell converter, which is optimally controlled by the proposed approach. The proposed method is simulated in

MATLAB Simulink platform and compared to numerous existing methods. The real and reactive powers of grid, are analyzed. From this analysis, it is concluded that the proposed method delivers better outcome than the existing ones. The overall power loss of the proposed method is almost 5% less when compared to that of the existing ones.

References

1. F. Blaabjerg and K. Ma, "Future on power electronics for wind turbine systems," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 1, no. 3, pp. 139–152, Sep. 2013.
2. H. Polinder, J. A. Ferreira, B. B. Jensen, A. B. Abrahamsen, K. Atallah, and R. A .Mc Mahon, "Trends in wind turbine generator systems," *IEEE J.Emerg. Sel. Topics Power Electron.* Vol. 1, no. 3, pp. 174–185, Sep. 2013.
3. L. Nousiainen, J. Puukko, A. Maki, T. Messo, J. Huusari, J. Jokipii,J. Viinamaki, D. T. Lobera, S. Valkealahti, and T. Suntio, "Photovoltaic generator as an input source for power electronic converters," *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 3028–3038, Jun. 2013.
4. W. Jinn-Chang and C. Chia-Wei, "A solar power generation system with a seven-*Electron.*, vol. 29, no. 7, pp. 3454–3462, Jul. 2014.
5. R. C. N. Pilawa-Podgurski, and D. J. Perreault, "Submodule integrated distributed maximum power point tracking for solar photovoltaic applications, "*IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2957–2967, Jun.2013.
6. T. A. Meynard, and H. Foch, "Multi-level conversion: High voltage choppers and voltage-source inverters," in *Proc. 23rd IEEE Power Electron. Spec. Conf.*, Jun. 29–Jul. 3, 1992, vol. 1, pp. 397–403.
7. J. S. Lai and F. Z. Peng, "Multilevel converters—A new breed of power converters," *IEEE Trans. Ind. Appl.*, vol. 32, no. 3, pp. 509–517, May/Jun.1996.
8. S. Kouro, M. Malinowski, K. Gopakumar, J. Pou, L. G. Franquelo, B.Wu,J. Rodriguez, M. A. Perez, and J. I. Leon, "Recent advances and industrial applications of multilevel converters," *IEEE Trans. Ind. Electron.*, vol. 57,no. 8, pp. 2553–2580, Aug. 2010.
9. A. Sanchez-Ruiz, M. Mazuela, S. Alvarez, G. Abad, and I. Baraia, "Medium voltage-high power converter topologies comparison procedure, for a 6.6 kV drive application using 4.5 kV IGBT modules," *IEEE Trans. Ind. Electron.*, vol. 59, no. 3, pp. 1462–1476, Mar. 2012.
10. G. Gateau, T. A. Meynard, and H. Foch, "Stacked multicell converter (SMC): Properties and design," in *Proc. 32nd IEEE Power Electron. Spec. Conf.*, 2001, vol. 3, pp. 1583–1588.
11. M.Annoukoubi, D. Rahiel, A. Allali, F. Kaddour, and M. Denaï, "Power quality enhancement in electricity grids with wind energy using multicell converters and energy storage," *Journal of Renewable and Sustainable Energy*, vol. 11, no. 1, p. 013302, 2019.
12. R. Boopathi, R. Jayanthi, and M. M. Ansari, "Maximum power point tracking-based hybrid pulse width modulation for harmonic reduction in Wind Energy Conversion Systems, "Computers & amp;amp; Electrical Engineering, vol. 86, pp. 106711, 2020.
13. M. Bašić, D. Vukadinović, I. Grgić, and M. Bubalo, "Energy efficient control of a standalone wind energy conversion system with AC current harmonics compensation," Control Engineering Practice, vol. 93, p. 104185, 2019.
14. B. Sahoo, S. K. Routray, and P. K. Rout, "Robust control approach for the integration o of DC-grid based Wind Energy Conversion System," IET Energy Systems Integration, vol. 2, no. 3, pp. 215–

225, 2020.and Technology, Transactions of Electrical Engineering, vol. 43, no. 4, pp. 1053–1073, 2019.