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Wind turbine damper optimization using machine learning technologies considering wake effects

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SUMMARY:
Wind turbine wake flow generally has larger turbulence intensity compared with free flow, which would result in larger damage to downstream wind turbines. However, there still has no research about wind turbine vibration considering wake effect. Meanwhile, although previous research had reduced wind turbine vibration by installing dampers, there is still no systematic global optimization method for wind turbine damper. The question that whether optimized damper without consideration about wake effect can be directly applied in wind turbines affected by wake or not is still not clear. To this end, this study first investigates wake effect on downstream wind turbine vibration. Then, tuned mass damper and rotational inerter double tuned mass damper are installed in wind turbine tower to control tower vibration. Innovatively, this study proposes a global optimization method for dampers based on radial basis function neural network and genetic algorithm, which is significantly accelerated by GPU acceleration technology. As well, wake effect on wind turbine dampers is studied by comparing optimized dampers with and without consideration of wake. Optimized dampers can reduce at most 44% tower bottom equivalent fatigue load. Numerical results can provide references for choosing damper and damper optimization in real engineering.

Keywords: wind turbine, vibration control, wake effect

1. INTRODUCTION

Wind turbine is utilized to harvest wind energy. For more energy output, wind turbine size grows rapidly, which causes excessive tower vibrations. Further, long-term vibration results in large tower bottom equivalent fatigue load (EFL), which is the primary reason for tower collapsing. Thus, investigating wind turbine tower vibration and how to control it get more and more important (Fitzgerald and Basu, 2013; Rezaei et al., 2018).

Therefore, this study controls wind turbine fore-aft vibration through installing dampers in it, as can be seen in Fig. 1. Both of TMD and rotational inerter double TMD (RIDTMD) are investigated. First, upstream wind turbine wake effects on downstream wind turbine vibrations are examined. Next, damper parameters are respectively optimized with and without upstream wind turbine wake effects. Damper parameters are compared with each other to study wake effects on damper optimization. This study innovatively presents an optimization method based on radial basis function neural network (RBFNN) and genetic algorithm (GA), which is greatly accelerated by GPU (graphic process unit) acceleration technology. Numerical results can help engineers properly choose and optimize dampers in real engineering.

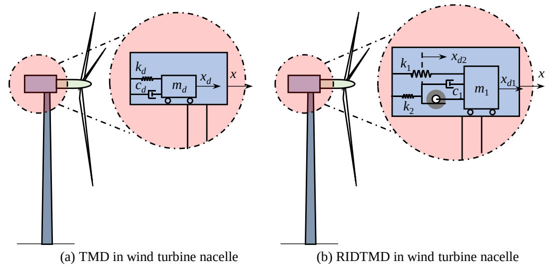

Figure 1. (a) TMD in wind turbine nacelle; (b) RIDTMD in wind turbine nacelle.

2. NUMERICAL METHODS

This study presents a novel structural dynamic analysis software for wind turbine (PyGAOWT), which is developed on the basis of AOWT (Liu et al., 2020). Fig. 2 (a) and (b) present hardware layer and software layer of PyGAOWT, respectively. Benefiting from GPU acceleration technology, PyGAOWT has significantly higher computing efficiency, as can be seen in Table 1. Meanwhile, this study proposes RBFNN- and GA-based optimization method, as can be seen in Fig. 3. Detailed formulae of RBFNN and GA can be referred to the study of Liu et al. (2021b).

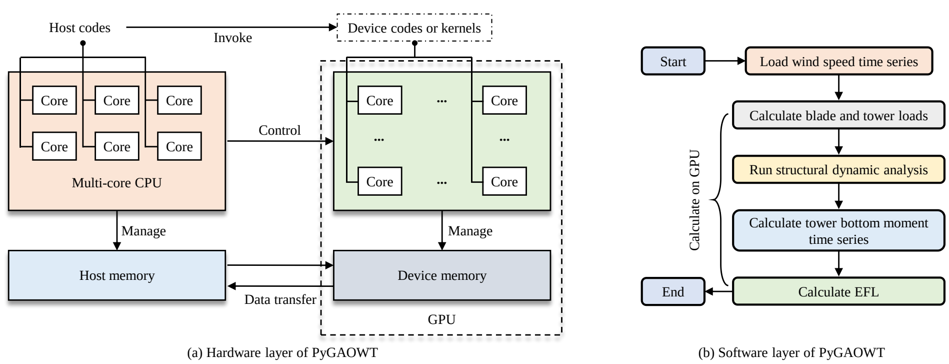

Figure 2. (a) hardware layer of PyGAOWT; (b) Software layer of PyGAOWT.

Table 1. Comparisons of computing efficiency between AOWT and PyGAOWT.

Number of cases	AOWT (min)	PyGAOWT (min)	AOWT / PyGAOWT
One single case	40.7	1.7	23.94
300 cases	12210	6.1	2000

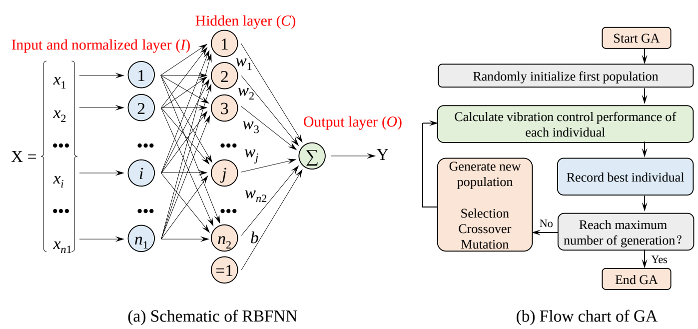

Figure 3. (a) schematic of RBFNN; (b) Flow chart of GA.

4. WAKE EFFECTS ON DAMPER OPTIMIZATION

There have two wind turbines, which line up along wind propagation direction. Four different wind turbine spacings are adopted, which are 2*D*, 4*D*, 6*D*, and 8*D* with *D* as wind turbine rotor radius. Four different wind speed distributions (C1 – 4) (Liu et al., 2021a) are considered. Wind turbine tower EFL are calculated for these four different spacings, when there has no TMD installed. EFLs are presented in Fig. 4. It can be stated that when wind turbine spacing is approximately 2*D*, wake effects between the wind turbines should be encountered owing to that it can significantly increase wind turbine EFL. Subsequently, PyGAOWT and RBFNN-GA-based optimization method are utilized to optimize TMD structural parameters when under wind conditions C2 – 4 (Liu et al., 2021a). Table 2 lists optimized TMD parameters. Fig. 5 shows EFL reduction ratios of these two wind turbines after applying TMD. RBFNN-GA-optimized TMDs improve by 13% compared with theoretically optimized ones, and they can reduce at most 40% wind turbine tower EFL.

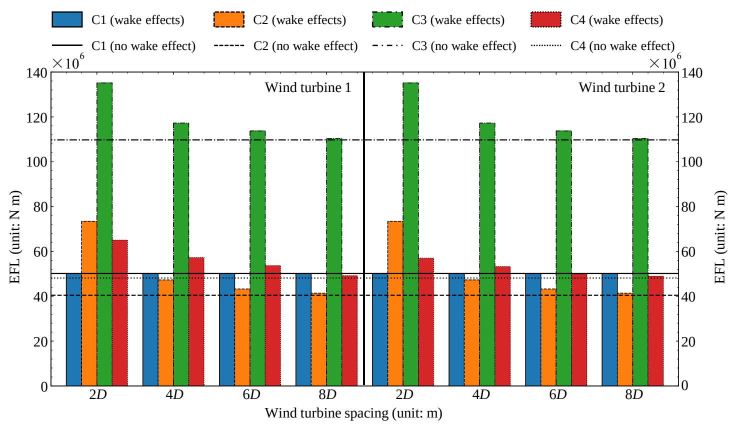

Figure 4. Wind turbine ELFs without damper when wake effect is considered and not considered.

Table 2. Optimized TMD parameters when under wind conditions C2 – 4.

Wind turbine 1				Wind turbine 2			
Case name	μ	v	ξ	Case name	μ	v	ξ
C2	0.135	1.01	0.19	C2	0.135	0.97	0.22
C3	0.135	1.15	0.29	C3	0.135	1.09	0.34
C4	0.135	0.94	0.11	C4	0.135	1.01	0.26

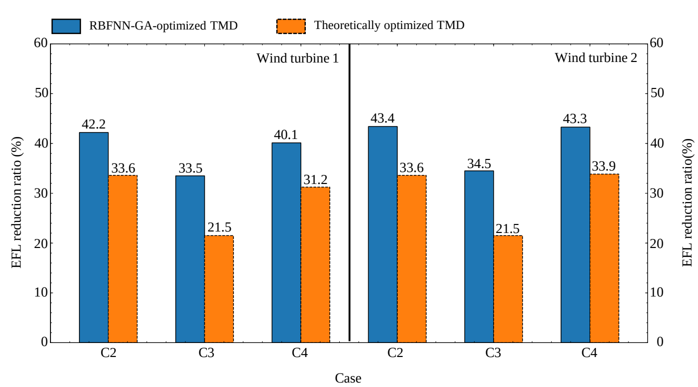

Figure 4. EFL reduction ratio with RBFNN-GA-optimized and theoretically optimized TMD.

5. COMPARISON BETWEEN TMD AND RIDTMD

RIDTMD is also applied to control wind turbine tower vibration in this section. In this section, wake effects are not considered. Dampers are optimized for only one wind turbine. Wind conditions C1 – 4 (Liu et al., 2021a) are adopted again. Optimized TMD and RIDTMD parameters are summarized in Table 3. Their corresponding EFL reduction ratios are listed in Table 4. TMD performs a little better than RIDTMD. Optimized TMD and RIDTMD can at most reduce 44% wind turbine tower EFL when under real wind distributions.

Table 3. Optimized TMD and RIDTMD structural parameters.

TMD				RIDTMD					
Case name	μ	v	ξ	Case name	μ	μ_1	ξ	β	v
C1	0.2100	1.1751	0.1769	C1	0.2100	1.6000	0.3946	0.9139	1.6000
C2	0.2089	1.0880	0.3108	C2	0.1886	1.2769	0.1402	0.4407	1.2576
C3	0.2100	0.9377	0.0882	C3	0.2100	0.6255	0.4390	0.9106	1.5999
C4	0.1998	0.9896	0.2253	C4	0.2100	0.4695	0.4149	0.1104	1.6000

Table 4. EFL reduction ratios of optimized TMD and RIDTMD.

TMD		Wind condition				RIDTMD		Wind condition			
		C1	C2	C3	C4			C1	C2	C3	C4
Optimized TMD	C1	48.53%	48.97%	36.73%	30.36%	Optimized RIDTMD	C1	49.03%	48.98%	37.41%	30.68%
	C2	49.16%	49.12%	36.35%	31.03%		C2	48.10%	48.07%	38.74%	32.09%
	C3	44.35%	44.28%	41.17%	38.26%		C3	43.58%	44.55%	39.63%	39.08%
	C4	41.28%	42.23%	33.98%	44.21%		C4	40.96%	41.77%	34.60%	43.59%

6. CONCLUSION

In this study, TMD and RIDTMD are installed at top of wind turbine tower to reduce tower vibration. Novel PyGAOWT and RBFNN-GA-based optimization tool are presented. From numerical results, following conclusions can be drawn: i) TMD performs a little better than RIDTMD, which is more appropriate in wind turbine vibration control; ii) Wind condition greatly affect damper optimization result. In real engineering applications, wind turbine damper should be optimized correspondingly according to local wind distribution; iii) When wind turbine spacing is approximately 2*D*, wake effects between them should be considered; iv) Optimized dampers reduce at mots 44% wind turbine tower EFL in this study.

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