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# ENHANCED SEISMIC RESILIENCE OF WIND TURBINES USING ADVANCED VIBRATION MITIGATION STRATEGIES

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**Abstract**

*As the global shift toward renewable energy accelerates, wind power has emerged as a crucial solution for reducing carbon emissions and promoting sustainability. However, the structural integrity of wind turbines (WT) in seismic-prone regions remains a significant challenge due to the potential impact of strong ground motions. This study explores advanced vibration mitigation strategies to enhance the seismic resilience of onshore WT towers. A range of innovative vibration control systems (VCS) is integrated into a benchmark WT structure to counteract earthquake-induced forces and minimize structural damage. Specifically, this research examines the implementation of KDamper-based designs, which extend traditional Tuned Mass Damper (TMD) technology by incorporating negative stiffness and damping elements. The optimization of these systems follows a constrained design methodology using seismic input from EC8 standards. A comparative analysis with a high-mass TMD demonstrates the superior performance of the KDamper approach in reducing structural responses under severe seismic loading. The findings highlight the potential of advanced VCS in safeguarding wind energy infrastructure, ensuring its stability and long-term operational efficiency in earthquake-prone environments.*

**Keywords:** Structural Dynamics, Seismic Protection, Wind Turbines, Negative Stiffness, KDamper, Tuned Mass Damper.


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# 1 INTRODUCTION

In recent decades, the deployment of onshore and offshore wind turbines (WTs) has expanded significantly to meet the rising demand for renewable energy. To maximize power generation, the modern design of WTs is characterized by large rotors mounted on tall, slender towers. However, these structural modifications have introduced considerable engineering challenges associated with the increased rotational and gravitational loads in combination with the environmental forces. The WTs face complex loading conditions, including aerodynamic forces from wind gusts, seismic activity in certain regions and in the case of offshore installations, hydrodynamic loads from waves and currents. These environmental forces can trigger excessive structural vibrations and fatigue phenomena in WTs, potentially leading to reduced energy production or even structural failure [1, 2].

To address these challenges, engineers and scientists have developed a wide range of vibration control systems (VCS) for wind turbines, typically classified as passive [3-6], active [7, 8], hybrid [9], or semi-active [10, 11]. Among these, passive systems have gained widespread acceptance in engineering applications [12-14] due to their cost-effectiveness, operational simplicity and reliability. Tuned Mass Dampers (TMDs), for instance, have demonstrated significant efficacy in reducing tower vibrations [3, 5], by positioning a secondary (auxiliary) mass near high-amplitude regions, such as the nacelle. In a conventional TMD, this mass is connected to the primary structure via a spring and a damper. Proper frequency tuning enables the secondary mass to counteract the tower's dominant modal response, dissipating the vibrational energy. Multiple TMDs can also be installed within the nacelle (two TMDs were used in [4]) to counter fore-aft and side-to-side responses, while strategic placement of these devices along the tower [15] helps to mitigate the effects of combined multiple hazards.

Recent innovations based on the TMD concept have expanded the spectrum of passive control solutions. The Pendulum Tuned Mass Damper (PTMD) [16] has demonstrated effectiveness in managing both wind-induced and moderate seismic vibrations [17] in WT structures. The Tuned Liquid Column Damper (TLCD) [18] employs fluid dynamics principles to counteract external forces compromising a feasible solution for enhancing the fatigue life of offshore wind turbines [19, 20]. Alternative approaches, including the Ball Vibration Absorber (BVA) [21], the tuned rolling-ball damper [22] and the spherical tuned liquid damper [23], have also been examined for the vibration control of WTs, contributing to the field's advancement.

Despite their proven effectiveness and widespread adoption, TMD-based devices pose certain drawbacks that may raise additional challenges or adversely affect their performance in WT applications. The requirement of a large auxiliary mass inside the nacelle for the TMD to be effective imposes structural and installation challenges due to space limitations. Furthermore, this mass increases the tower's axial load and elevates its center of gravity, potentially leading to higher-order dynamic phenomena, especially in WTs with tall, slender towers. Moreover, the parameters of the TMD depend significantly on seasonal temperatures [24], hindering its optimal tuning. Without proper tuning, the performance of the TMD is significantly reduced.

The KDamper [25] has emerged as an innovative alternative to conventional TMDs and is characterized by the incorporation of a negative stiffness (NS) element alongside an auxiliary mass, a damper and a spring. The NS element indirectly increases the inertia of the additional oscillating mass, amplifying vibration absorption and eliminating the requirement for a large additional mass to be effective, thereby overcoming the main drawback of TMD which is the need for large parasitic masses. Additionally, compared to the TMD, the KDamper more effectively controls the tuning of its parameters and provides vibration mitigation across a wider frequency range. Moreover, while the NS element reverses the conventional direction of the stiffness force, careful design ensures that the device remains statically and dynamically stable within its operational range. Compared to other traditional NS isolators, such as the Quasi-Zero-Stiffness (QZS) oscillators [26], the KDamper also manages to maintain the overall static stiffness of the system.

Several KDamper variants, such as the Extended KDamper (EKD) [27], the Seismic Base Absorber (SBA) [28], and the Enhanced KDamper (ENKD) [29], have further refined the technology and improved the overall performance of the original KDamper device. These advanced variations incorporate modifications in their structural design and mechanical properties, leading to superior adaptability and efficiency in different engineering applications. The SBA and ENKD, in particular, integrate inerter elements [30], which significantly enhance the inertial effect. This enhancement enables these devices to perform efficiently even under extreme loading conditions, making them ideal for applications where traditional dampers might be less effective. To fully exploit the potential of KDamper-based devices in providing effective vibration control, it is essential to ensure their optimal configuration through optimization methodologies [31-33], precise mechanical design strategies [34, 35], and the careful selection of an appropriate negative stiffness (NS) mechanism [36-38] to ensure the proper realization of the NS elements. Proper tuning of these parameters is critical in achieving the desired seismic performance while maintaining structural stability. Over the years, the KDamper, EKD, SBA, and ENKD devices have been extensively investigated across various engineering fields. These applications span across multiple domains, including the horizontal seismic protection of multi-story building structures [29, 32, 33, 39-44], vertical seismic absorption applications [45, 46], horizontal seismic protection systems for bridge structures [47], and vibration mitigation in wind turbine towers due to aerodynamic loads [48, 49].

This paper explores the seismic protection of onshore wind turbines (WT) through the implementation of innovative vibration control systems (VCS). The study focuses on the KDamper concept, an advanced extension of the traditional Tuned Mass Damper (TMD), which integrates appropriate negative stiffness and damping elements to enhance vibration mitigation efficiency. The NS force is exactly in phase with the inertia force of the additional mass, thus indirectly increasing the inertia force, and as a result, significantly reducing the mass requirements of the VCS. A benchmark WT tower is analyzed using a detailed dynamic model composed of prismatic beam elements, with numerical simulations conducted through an in-house developed MATLAB code. The proposed VCS configurations are optimized using a constrained engineering-criteria driven optimization methodology that considers critical engineering, manufacturing, and geometric limitations, ensuring practical feasibility. Seismic excitation inputs are selected based on EC8 provisions, with a database of artificial accelerograms generated to match the EC8 design acceleration spectrum using the SeismoArtif software. A comparative evaluation against a conventional Tuned Mass Damper (TMD), which requires significantly more additional mass (20 times higher), underscores the enhanced performance of KDamper-based configurations. The results reveal that the proposed approach substantially improves the seismic resilience of onshore WT structures, by reducing the WT tower relative to the ground displacement and WT base shear, while retaining the VCS-related displacements in reasonable ranges.

## 2 METHODOLOGY AND MATHEMATICAL MODELLING

In this paper, an onshore wind turbine of length X, and variable tubular cross-section X is examined, as illustrated in Fig. 1. The wind turbine tower has a base diameter of 8.43 *m* with steel thickness 4.8 *cm*, and a top diameter of 3.87 *m* with thickness 2.5 *cm*. The Young's modulus is 210 *GPa*, and the steel density is equal to 8.5 $tn/m^3$. The inertial forces applied by the mechanical parts (nacelle, rotor and blades) are accounted for by introducing an additional concentrated mass $m_{NAC}$ = 403.22 *tn* [44] at the top of the WT tower, as presented in Fig. 1.

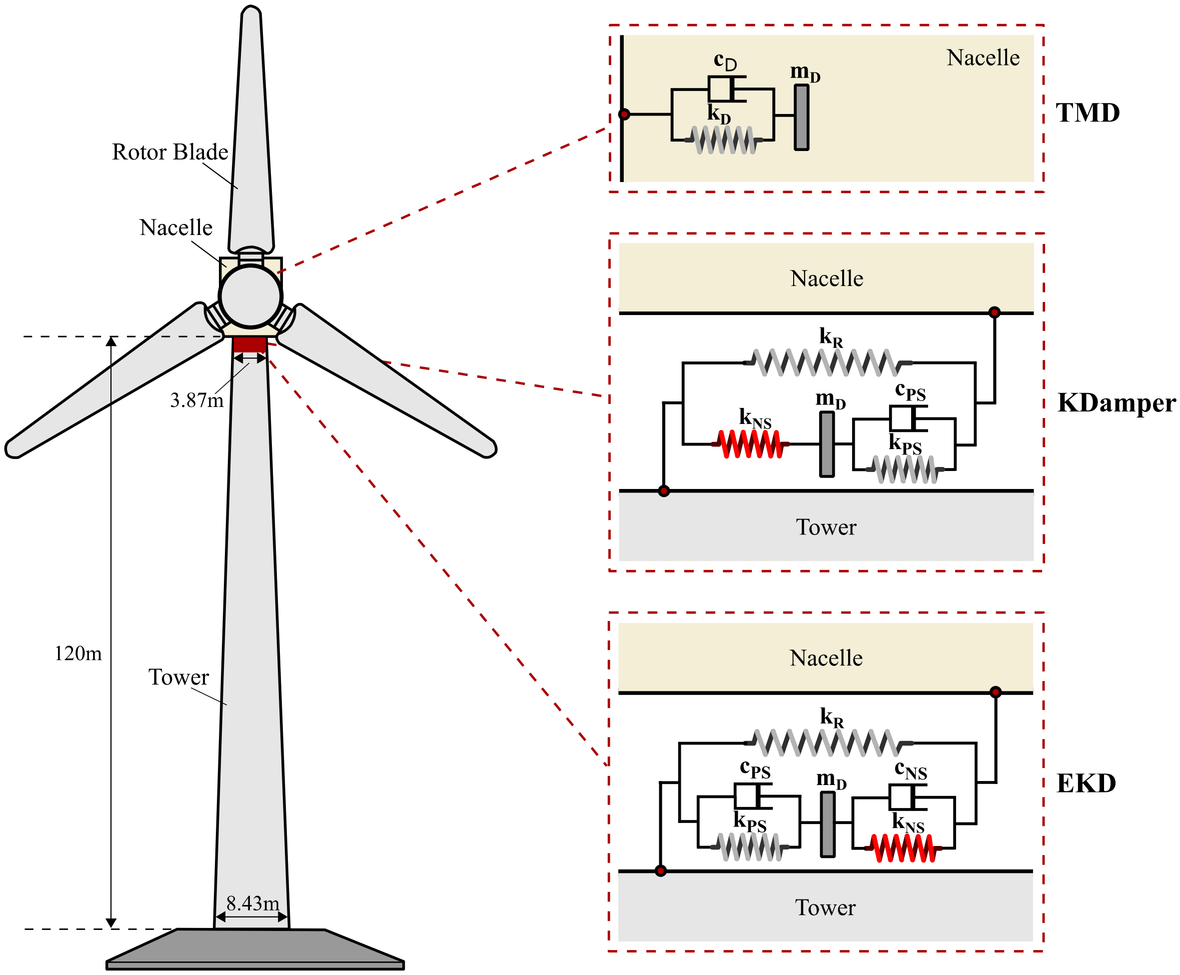


Figure 1: Vibration mitigation configurations examined for the onshore wind turbine tower: Tuned Mass Damper (TMD), KDamper, and extended KDamper (EKD).

The WT tower is modelled as an assemblage of prismatic beam elements. The dynamic DoFs (degrees of freedom) are the sway ones. Additional assumptions made for the of the WT tower are 1) the WT tower remains elastic during the analysis, 2) SSI (soil-structure-interaction) effects are not taken into consideration, and 3) no axial DoFs are accounted for. The equations of motion can be thus formulated in a matrix form as follows:

$$\left[M_{WT-VCS}\right]\{\ddot{u}\}+\left[C_{WT-VCS}\right]\{\dot{u}\}+\left[K_{WT-VCS}\right]\{u\}=-\left[M_{WT-VCS}\right][I]a_G(t) \tag{1}$$

where $[M_{WT\text{-}VCS}]$, $[M_{WT\text{-}VCS}]$, and $[M_{WT\text{-}VCS}]$ are the mass, stiffness, and damping matrices of the controlled WT with the VCS, $\{u\}$ is the vector of the nodal relative to the ground displacements, and $a_G(t)$ is the ground acceleration excitation. The equations of motion, Eq. (1), should be modified with respect to the implemented VCS. More specifically, the additional mass of the TMD, $m_D$, is installed either at the top of the WT tower or inside the nacelle, supported by a positive stiffness element $k_D$ and a linear damper $c_D$. The TMD parameters can be calculated with respect to the TMD design variables 1) mass ratio ($\mu_{TMD}$), 2) tuning ratio ($t_D$), and 3) damping ratio ($\zeta_D$), as follows:

$$m_D = \mu_D m_{NAC} \tag{2.1}$$

$$f_D = t_D f_{(1)} = \sqrt{k_D / m_D} \Big/ 2\pi \tag{2.2}$$

$$c_D = 2\zeta_D \omega_D m_D = 2\zeta_D (2\pi f_D) m_D \tag{2.3}$$

where $f_{(1)}$ is the fundamental frequency of the uncontrolled WT. When using KDamper-based configurations (KDamper or EKD), the nacelle is no longer rigidly connected to the WT tower but is instead mounted on a KDamper-based system. In this setup, the concentrated mass $m_{NAC}$ is linked to the top of the WT tower through a positive stiffness connection $k_R$, while the additional EKD mass $m_D$ is connected to $m_{NAC}$ via a negative stiffness element $k_{NS}$ and a parallel linear damper $c_{NS}$. Additionally, $m_D$ is also attached to the top of the WT tower using a positive stiffness element $k_{PS}$ and a parallel linear damper $c_{PS}$. The EKD parameters can be calculated with respect to the EKD design variables 1) mass ratio ($\mu_D$), 2) tuning frequency of the additional oscillating mass ($f_{EKD}$), 3) equivalent stiffness of the nacelle-tower layer ($k_{NAC-EKD}$), 4) nominal frequency of the nacelle-tower layer ($f_{NAC-EKD}$), and 5) damping ratios of the added linear dampers ($\zeta_{PS}$, $\zeta_{NS}$), as follows:

$$m_D = \mu_D m_{NAC} \tag{3.1}$$

$$f_{EKD} = \sqrt{\left(k_{NS} + k_{PS}\right) / m_D} \Big/ 2\pi \tag{3.2}$$

$$k_{NAC-EKD} = k_R + \left(k_{NS} k_{PS}\right) \big/ \left(k_{NS} + k_{PS}\right) \tag{3.3}$$

$$f_{NAC-EKD} = \sqrt{k_{NAC-EKD} / \left(m_{NAC} + m_D\right)} \Big/ 2\pi \tag{3.4}$$

$$c_{NS,PS} = 2\zeta_{NS,PS} (2\pi f_{EKD}) m_D \tag{3.5}$$

## 3 OPTIMAL DESIGN OF KDAMPER CONFIGURATIONS

After formulating the equations of motion for the controlled onshore WT with the examined VCS (Eq. (1)), the next step is to identify the optimal VCS parameters to achieve the most effective seismic protection strategy. The performance of most VCS systems is largely influenced by their frequency and damping ratio. Several optimization techniques have been proposed to define the key design parameters of such vibration absorbers. However, due to the complexity of KDamper-based configurations, conventional min–max (H∞) approaches prove to be ineffective. In this paper, the proposed KDamper-based VCS are designed considering engineering criteria, as well as manufacturing and geometric constraints. The VCS parameters are determined using constrained optimization algorithms, an efficient method for designing practical and robust vibration control devices. To obtain the optimal values of the independent design parameters for all examined VCS, this study employs the Harmony Search (HS) algorithm, a novel metaheuristic optimization technique.

The primary function of the VCS is to prevent structural failure in the event of a severe earthquake. Strong seismic events can be induced by different types of accelerograms, including synthetic records, real earthquake excitations, and artificial accelerograms designed to align with a specific response spectrum, with the latter being the most suitable. In this paper, a database of EC8 design acceleration response spectrum artificial accelerograms is generated and used as input in the optimization process. The target spectrum is based on the EC8 standard and is defined by the following characteristics: ground type C, spectral acceleration of 0.36 $g$, spectrum type I, and importance class II. The calculation method applied in this research is the Artificial Accelerogram Generation and Adjustment method, implemented using the SeismoArtif software.

A crucial factor to consider when using negative stiffness elements in a vibration control system like the EKD is the static and dynamic stability of the controlled WT. To address this, possible variations in all stiffness elements are included in the EKD design process by introducing simultaneous perturbations $\varepsilon$ in all stiffness components. A constraint imposed in the optimization process is that the determinant of the controlled WT stiffness matrix is positive, accounting the aforementioned perturbations.

The stiffness elements $k_R$ and $k_{PS}$ are determined based on the negative stiffness $k_{NS}$ and the nominal frequency of the nacelle-tower layer $f_{NAC-EKD}$. The additional mass of the EKD is assumed to be constant and much lower than that of the TMD due to the effect of negative stiffness on the added mass's effective inertia, and it is set at $\mu_D = 0.1\%$. In this study, variations in stiffness elements are set as $\varepsilon_R = \varepsilon_{NS} = \varepsilon_{PS} = 5\%$. Therefore, the design variables optimized for the EKD system are:

1. The nominal frequency of the nacelle-tower layer $f_{NAC-EKD}$, which varies between 0.1 $Hz$ and 1 $Hz$. The same range applies to the KDamper system $f_{NAC-KDamper}$.
2. The negative stiffness element $k_{NS}$, which varies from 0 $kN/m$ to -100 $kN/m$ per $tn$ of concentrated mass $m_{NAC}$.
3. The linear dampers $c_{NS}$ and $c_{PS}$, which vary from 0 $kNs/m$ to 5 $kNs/m$ per $tn$ of concentrated mass $m_{NAC}$.

A geometric constraint is applied to the stroke of the additional oscillating EKD mass, limiting it to half of the top WT diameter (a similar constraint is imposed in the TMD design). Another constraint is placed on the relative displacement between the nacelle and the top of the WT tower for operational reasons: $u_{NAC-TOW} = u_{NAC} - u_{TOW}(h = 120m) < 0.5m$. Finally, the optimization process focuses on minimizing the maximum absolute value of the base shear, which is determined as the mean of the highest values from dynamic analyses of all artificial accelerograms in the database.

## 4 NUMERICAL RESULTS

After completing the optimization process, the optimized VCS parameters are determined. The optimal TMD tuning frequency ratio was found to be $t_D$ = 0.827, indicating that higher modes contribute when ground motion acceleration occurs. This suggests that tuning the TMD to the fundamental frequency of the primary structure is not always the best approach. The optimal TMD damping ratio was $\zeta_D$ = 6 %. The implementation of the TMD reduced the base shear from 4825 *kN* to 4607 *kN*, a decrease of 4.5 %. Additionally, the top WT tower displacement was reduced from 58.3 *cm* to 46.5 *cm*, representing a 20.2 % reduction.

For the KDamper system, the optimal nominal frequency of the nacelle-tower layer was $f_{NAC\text{-}KDamper}$ = 0.54 *Hz*. The NS element was optimized to $k_{NS}$ = -61.3 *kN/m* per *tn* of $m_{NAC}$, and the artificial damper value was $c_{PS}$ = 907 *kNs/m*. In the EKD, the optimal nominal frequency was $f_{NAC\text{-}EKD}$ = 0.226 *Hz*, the NS element was $k_{NS}$ = -42.4 *kN/m* per tn of $m_{NAC}$, the artificial damper value was $c_{NS}$ = 155 *kNs/m*, and the artificial damper value was $c_{PS}$ = 21 *kNs/m*. The KDamper achieved a significant reduction in base shear, lowering it from 4825 *kN* to 2628 *kN*, a 45.5 % decrease. Additionally, the top WT tower displacement was reduced from 58.3 *cm* to 24.1 *cm*, a reduction of 58.7 %. The EKD performed even better, reducing the base shear from 4825 *kN* to 1902 *kN*, a 60.6 % decrease, while also reducing the top WT tower displacement from 58.3 *cm* to 21.5 *cm*, a 63.1 % reduction. The results clearly show that KDamper-based designs outperform the TMD with significantly less added mass. Figs. 2-3 presents the dynamic responses of the WT, the WT-TMD and the WT-EKD for 2 artificial accelerograms.

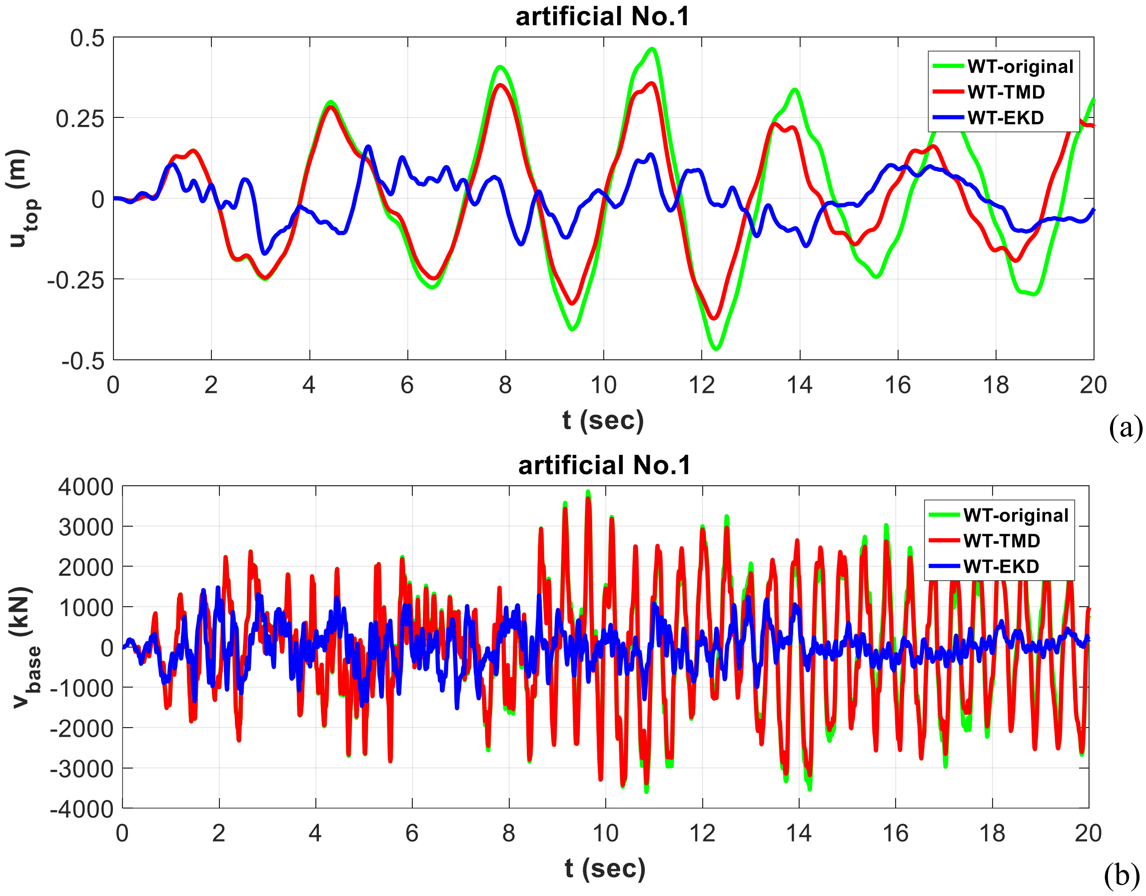


Figure 2: (a) Top WT tower displacement and (b) total WT base shear of the primary onshore WT, the WT equipped with a TMD, and the WT equipped with an EKD, for artificial accelerogram No.1.

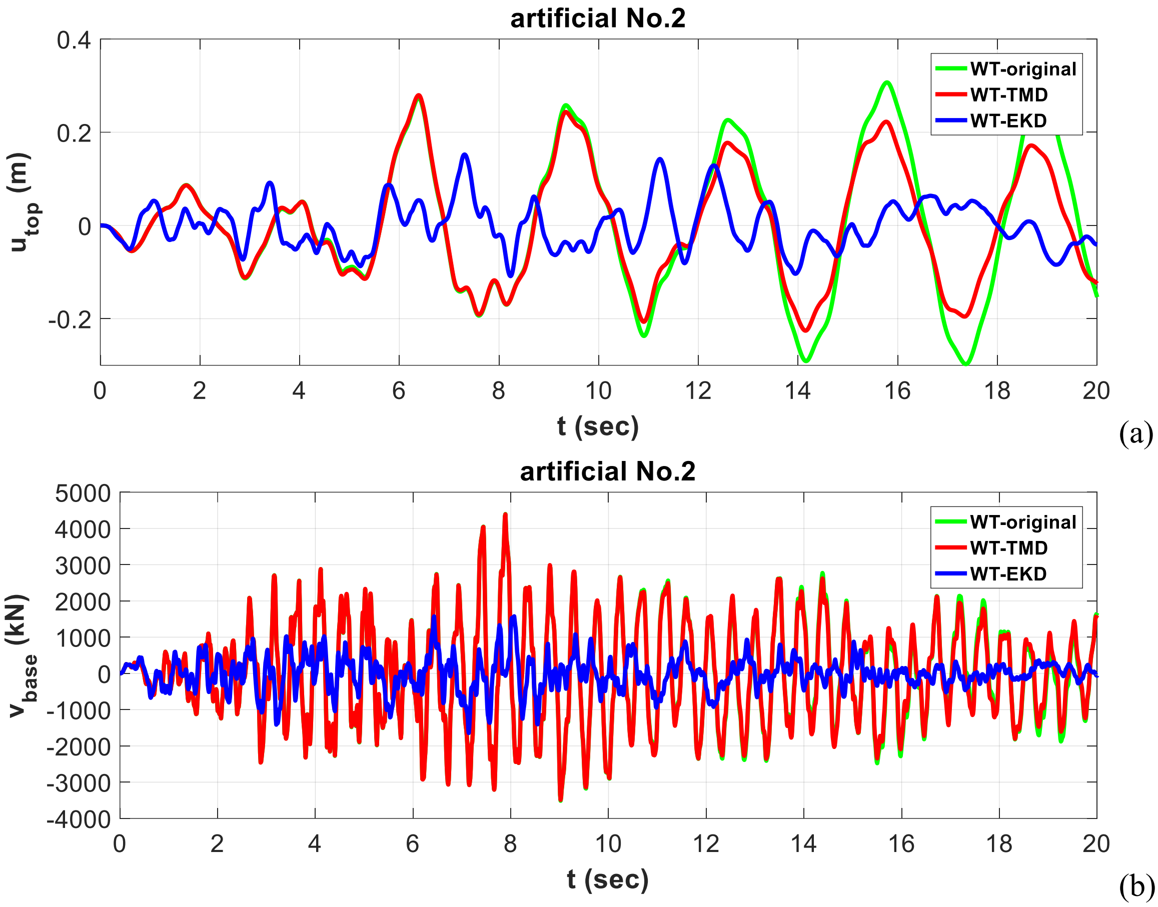


Figure 3: (a) Top WT tower displacement and (b) total WT base shear of the primary onshore WT, the WT equipped with a TMD, and the WT equipped with an EKD, for artificial accelerogram No.2.

## 5 CONCLUSIONS

This paper explores the use of KDamper-based configurations for improving the seismic resilience of onshore wind turbines. The dynamic behavior of the WT tower is modeled using prismatic beam elements, and a custom MATLAB-based software employing the Newmark-β method is developed for numerical analysis. A constrained optimization approach is introduced to design the vibration control system (VCS), ensuring it meets engineering standards as well as manufacturing and geometric constraints. The excitation input follows EC8 provisions, with a generated database of artificial accelerograms compatible with the design spectrum. The study highlights several key findings: the developed dynamic model is effective in integrating different VCS solutions and optimizing their performance for seismic protection; KDamper-based designs offer advantages over traditional mass-dependent vibration absorbers, requiring significantly less additional mass; compared to conventional TMDs, KDamper-based solutions provide substantially greater reductions in structural forces and displacements; and the EKD, as an extension of the KDamper concept, emerges as a particularly effective and reliable solution, maintaining strong performance across different earthquake records while requiring only moderate damping and stiffness adjustments.

## REFERENCES


[1] Chou Jui-Sheng, Tu Wan-Ting, Failure analysis and risk management of a collapsed large wind turbine tower. *Engineering Failure Analysis*, **18(1)**, 295–313, 2011. DOI: https://doi.org/10.1016/j.engfailanal.2010.09.008.

[2] Yao Li, Caichao Zhu, Chaosheng Song, Jianjun Tan, Research and development of the wind turbine reliability. *International Journal of Mechanical Engineering and Applications*, **6(2)**, 35-45, 2018. DOI: https://doi.org/10.11648/j.ijmea.20180602.14.

[3] P.J. Murtagh, A. Ghosh, B. Basu, B.M. Broderick, Passive control of wind turbine vibrations including blade/tower interaction and rotationally sampled turbulence. *Wind Energy*, **11(4)**, 305–317, 2008. DOI: https://doi.org/10.1002/we.249.

[4] M.A. Lackner, M.A. Rotea, Passive structural control of offshore wind turbines. *Wind Energy*, **14(3)**, 373–388, 2011. DOI: https://doi.org/10.1002/we.426.

[5] G.M. Stewart, M.A. Lackner, The impact of passive tuned mass dampers and wind–wave misalignment on offshore wind turbine loads. *Engineering Structures*, **73**, 54-61, 2014. DOI: https://doi.org/10.1016/j.engstruct.2014.04.045.

[6] S. Avila, M. Shzu, M. Morais, Z. Prado, Numerical modeling of the dynamic behavior of a wind turbine tower. *Advances in Vibration Engineering*, **4**, 2016.

[7] Zhang Zili, Nielsen Søren, Blaabjerg Frede, Zhou Dao, Dynamics and control of lateral tower vibrations in offshore wind turbines by means of active generator torque. *Energies*, **7(11)**, 7746–7772, 2014. DOI: https://doi.org/10.3390/en7117746.

**[8]** V. Maldonado, M. Boucher, R. Ostman, M. Amitay, Active Vibration Control of a Wind Turbine Blade Using Synthetic Jets. *International Journal of Flow Control*, **1(4)**, 227-238, 2009. DOI: https://doi.org/10.1260/1756-8250.1.4.227.

[9] F. Ricciardelli, A.D. Pizzimenti, M. Mattei, Passive and active mass damper control of the response of tall buildings to wind gustiness. *Engineering Structures*, **25(9)**, 1199–1209, 2003. DOI: https://doi.org/10.1016/S0141-0296(03)00068-3.

[10] F. Casciati, J. Rodellar, U. Yildirim, Active and semi-active control of structures – theory and applications: A review of recent advances. *Journal of Intelligent Material Systems and Structures*, **23(11)**, 1181–1195, 2012. DOI: https://doi.org/10.1177/1045389X12445029.

[11] F. Weber, Optimal semi-active vibration absorber for harmonic excitation based on controlled semi-active damper. *Smart Materials and Structures*, **23(9)**, 2014. DOI: https://dx.doi.org/10.1088/0964-1726/23/9/095033.

[12] T.T. Soong, G.F. Dargush, *Passive energy dissipation systems in structural engineering*. Wiley, 1997.

[13] F. Casciati, F. Giuliano: Performance of multi-TMD in the towers of suspension bridges. *Journal of Vibration and Control*, **15(6)**, 821–847, 2009. DOI: https://doi.org/10.1177/1077546308091455

[14] S.M. Nigdeli, G. Bekdaş, Optimum tuned mass damper design in frequency domain for structures. *KSCE Journal of Civil Engineering*, **21(3)**, 912–922, 2017. DOI: https://doi.org/10.1007/s12205-016-0829-2.

[15] H. Zuo, K. Bi, H. Hao, Using multiple tuned mass dampers to control offshore wind turbine vibrations under multiple hazards. *Engineering Structures*, **141**, 303–315, 2017. DOI: https://doi.org/10.1016/j.engstruct.2017.03.006.

[16] S. Chapain, A.M. Aly, Vibration attenuation in wind turbines: A proposed robust pendulum pounding TMD. *Engineering Structures*, **233**, 2021. DOI: https://doi.org/10.1016/j.engstruct.2021.111891.

[17] V.J. García, E.P. Duque, J.A. Inaudi, C.O. Márquez, J.D. Mera, A.C. Rios: Pendulum tuned mass damper: optimization and performance assessment in structures with elasto-plastic behavior. *Heliyon*, **7(6)**, 2021. DOI: https://doi.org/10.1016/j.heliyon.2021.e07221.

[18] S.D. Xue, J.M. Ko, Y.L. Xu: Tuned liquid column damper for suppressing pitching motion of structures. *Engineering Structures*, **22(11)**, 1538-1551, 2000. DOI: https://doi.org/10.1016/S0141-0296(99)00099-1.

[19] B. Basu, S. Colwell, Vibration control of an offshore wind turbine with a tuned liquid column damper. *11th International Conference on Civil, Structural and Environmental Engineering*, 2007.

[20] S. Colwell, B. Basu, Tuned liquid column dampers in offshore wind turbines for structural control. *Engineering Structures*, **31(2)**, 358-368, 2009. DOI: https://doi.org/10.1016/j.engstruct.2008.09.001.

[21] Z.L. Zhang, J.B. Chen, J. Li, Theoretical study and experimental verification of vibration control of offshore wind turbines by a ball vibration absorber. *Structure and Infrastructure Engineering*, **10(8)**, 1087–1100, 2013. DOI: https://doi.org/10.1080/15732479.2013.792098

[22] J. Chen, C.T. Georgakis, Tuned rolling-ball dampers for vibration control in wind turbines. *Journal of Sound and Vibration*, **332(21)**, 5271-5282, 2013. DOI: https://doi.org/10.1016/j.jsv.2013.05.019.

[23] J.-L. Chen, C.T. Georgakis, Spherical tuned liquid damper for vibration control in wind turbines. *Journal of Vibration and Control*, **21(10)**, 1875-1885, 2015. DOI: https://doi.org/10.1177/1077546313495911.

[24] B. Weber, G. Feltrin, Assessment of long-term behavior of tuned mass dampers by system identification. *Engineering Structures*, **32(11)**, 3670–3682, 2010. DOI: https://doi.org/10.1016/j.engstruct.2010.08.011

[25] I.A. Antoniadis, S.A. Kanarachos, K. Gryllias, I.E. Sapountzakis, KDamping: A stiffness based vibration absorption concept. *Journal of Vibration and Control*, **24(3)**, 588–606, 2018. DOI: https://doi.org/10.1177/1077546316646514.

[26] A. Carrella, M.J. Brennan, T.P. Waters, Static analysis of a passive vibration isolator with quasi-zero-stiffness characteristic. *Journal of Sound and Vibration*, **301(3-5)**, 678–689, 2007. DOI: https://doi.org/10.1016/j.jsv.2006.10.011.

[27] K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, Constrained optimal design of seismic base absorbers based on an extended KDamper concept. *Engineering Structures*, **226**, 2021. DOI: https://doi.org/10.1016/j.engstruct.2020.111312.

[28] K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, Feasibility Assessment of Stiff Seismic Base Absorbers. *Journal of Vibration Engineering & Technologies*, **10**, 37–53, 2021. DOI: https://doi.org/10.1007/s42417-021-00362-2.

[29] E. Sapountzakis, G. Florakis, K. Kapasakalis, Design and performance assessment of base isolated structures supplemented with vibration control systems. *Buildings*, **14(4)**, 2024. DOI: https://doi.org/10.3390/buildings14040955.

[30] M.C. Smith, Synthesis of Mechanical Networks: The Inerter. *IEEE Transactions on Automatic Control*, **47(10)**, 1648-1662, 2002. DOI: 10.1109/TAC.2002.803532.

[31] G.I. Florakis, K.A. Kapasakalis, E.J. Sapountzakis, I.A. Antoniadis, Multi-Objective Optimization of a Seismic Base Absorber Incorporating Negative Stiffness. *29th International Congress on Sound and Vibration (ICSV29)*, Prague, Czech Republic, July 9-13, 2023.

[32] G.I. Florakis, K.A. Kapasakalis, E.J. Sapountzakis, Simplified design approach of a negative stiffness-based seismic base absorber via multi-objective optimization. *Soil Dynamics and Earthquake Engineering*, **189**, 2025. DOI: https://doi.org/10.1016/j.soildyn.2024.109092.

[33] G.I. Florakis, K.A. Kapasakalis, E.J. Sapountzakis, Frequency-domain optimization of seismically isolated structures enhanced with negative stiffness devices. *Mechanical Systems and Signal Processing*, **228**, 2025. DOI: https://doi.org/10.1016/j.ymssp.2025.112375.

[34] G.I. Florakis, K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, Dimensioning and realistic design of a novel based negative stiffness seismic isolator. *Journal of Physics: Conference Series*, **2647(25)**, 2024. DOI: https://doi.org/10.1088/1742-6596/2647/25/252020.

[35] A. Mantakas, M. Kalderon, K.A. Chondrogiannis, K.A. Kapasakalis, E. Chatzi, I. A. Antoniadis, E.J. Sapountzakis, Experimental testing and numerical validation of the extended kdamper: A negative stiffness-based vibration absorber. *Engineering Structures*, **321**, 2024. DOI: https://doi.org/10.1016/j.engstruct.2024.118894.

[36] G.I. Florakis, K.A. Kapasakalis, E.J. Sapountzakis, I.A. Antoniadis, Seismic Base Absorber with a Novel Negative Stiffness Mechanism for the Horizontal Seismic Protection of Structures. *28th International Congress on Sound and Vibration (ICSV28)*, Singapore, July 24-28, 2022.

[37] G.I. Florakis, K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, A Novel Seismic Base Isolation Device for the Horizontal Protection of Structures Using a Negative Stiffness Mechanism with Gas Springs. *13th International Congress on Mechanics (13HSTAM 2022)*, Patras, Greece, August 24-27, 2022.

[38] G.I. Florakis, I.A. Antoniadis, E. J. Sapountzakis, A novel gas spring based negative stiffness mechanism for seismic protection of structures. *Engineering Structures*, **291**, 2023. DOI: https://doi.org/10.1016/j.engstruct.2023.116389.

[39] K.A. Kapasakalis, G.I. Florakis, I.A. Antoniadis, E.J. Sapountzakis, Seismic protection of multi-story structures with novel vibration absorption devices combining negative stiffness and inerter. *8th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2021)*, pp. 4026–4045, Athens, Greece, June 28-30, 2021. DOI: https://doi.org/10.7712/120121.8765.19225.

[40] G.I. Florakis, K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, Novel Negative Stiffness Stiff Seismic Base Absorbers for Horizontal Seismic Protection of Structures. *10th International Congress on Computational Mechanics (10th GRACM)*, Athens, Greece, July 5-7, 2021.

[41] K.A. Kapasakalis, G.I. Florakis, I.A. Antoniadis, E.J. Sapountzakis, Seismic Protection of Multi Story Building Structures with Distributed KDamper Devices. *27th International Congress on Sound and Vibration (ICSV27)*, Prague, Czech Republic, July 11-16, 2021.

[42] K.A. Kapasakalis, G.I. Florakis, E.J. Sapountzakis, I.A. Antoniadis, Seismic Protection of Multi-Story Building Structures with Geometric Nonlinear Negative Stiffness-Based Oscillator. *28th International Congress on Sound and Vibration (ICSV28)*, Singapore, July 24-28, 2022.

[43] A.G. Mantakas, K.A. Kapasakalis, A.E. Alvertos, I.A. Antoniadis, E.J. Sapountzakis, A negative stiffness dynamic base absorber for seismic retrofitting of residential buildings. *Structural Control and Health Monitoring*, **29(12)**, 2022. DOI: https://doi.org/10.1002/stc.3127.

[44] K. Kapasakalis, A. Mantakas, M. Kalderon, M. Antoniou, E. Sapountzakis, Performance evaluation of distributed extended kdamper devices for seismic protection of mid-rise building structures. *Journal of Earthquake Engineering*, **28(4)**, 972-997, 2023. DOI: https://doi.org/10.1080/13632469.2023.2226227.

[45] K.A. Kapasakalis, I.A. Antoniadis, E.J. Sapountzakis, Stiff vertical seismic absorbers. *Journal of Vibration and Control* **28(15-16)**, 1937–1949, 2022. DOI: https://doi.org/10.1177/10775463211001624.

[46] A.E. Gkikakis, K.A. Kapasakalis, E.J. Sapountzakis, Comprehensive design optimization of vertical seismic absorbers incorporating sensitivity and robust analysis: A case study of the kdamper. *Engineering Structures*, **301**, 2024. DOI: https://doi.org/10.1016/j.engstruct.2023.117303.

[47] E.J. Sapountzakis, P.G. Syrimi, I.A. Pantazis, I.A. Antoniadis, KDamper concept in seismic isolation of bridges with flexible piers. *Engineering Structures*, **153**, 525–539, 2017. DOI: https://doi.org/10.1016/j.engstruct.2017.10.044.

[48] K. Kapasakalis, A. Gkikakis, E. Sapountzakis, E. Chatzi, A. Kampitsis, Multi-objective optimization of a negative stiffness vibration control system for offshore wind turbines. *Ocean Engineering*, **303**, 2024. DOI: https://doi.org/10.1016/j.oceaneng.2024.117631.

[49] A. Kampitsis, K. Kapasakalis, L. Via-Estrem, An integrated FEA-CFD simulation of offshore wind turbines with vibration control systems. *Engineering Structures*, **254**, 2022. DOI: https://doi.org/10.1016/j.engstruct.2022.113859.