IECON 2022 Tutorial Proposal Form

Title of the Proposal

Advances in Design and Control for Linear Machines and Drive Systems

Presenter(s) (Title, name, affiliation)

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Brief description (Not more than 600 words)

The main subject of the tutorial is linear induction motors (LIMs). Starting from a brief structural description of such motors, their main applications will be exposed in the tutorial with specific reference to MAGLEV (Magnetically Levitation) vehicles, urban people movers (such as linear metro, light railway, *etc.*), launchers, actuators for industry and automotive, *etc*. As a first step, the main differences between rotating and linear induction motors will be highlighted, focusing on the aspects of static and dynamic end effects as well as transversal edge effects. The typical structure of LIMs will be treated, with specific reference to secondary sheet and primary winding configurations.

Single-sided LIMs (S-LIMs) and Double-sided ones (D-LIMs) will be described in detail, focusing on normal force effects. Design criteria of LIMs will be specifically exposed, emphasizing the main differences with the classic rotating induction motor design, caused by the presence of large air-gaps, high leakage inductances as well as the end effects. Both static and dynamic models of LIMs will be introduced, including the so-called end-effects, magnetic saturation, non-linear traits influenced by PWM modulation, and so on. Suitable parameter estimation methods will be then described. Afterwards, control techniques specifically devised for LIMs, like field-oriented control, input-output feedback linearization control, active disturbance rejection control, model predictive control, efficiency optimization control, etc., will be introduced in detail. Finally, sensorless techniques with strong robustness capability specifically developed for LIMs will be shown.

Presentation duration (2.5 hours in total)

- Introduction on Linear Motors (LMs)
  - History and categories of LMs — 10 minutes
  - Potential applications of LMs — 15 minutes
- Design of LIMs
  - Key points/characteristics of LIMs — 15 minutes
  - Equivalent circuits of LIMs — 10 minutes
  - Design and performance of LIMs — 10 minutes
  - Several LIM prototypes — 15 minutes

- Parameter Estimation of LIMs 10 minutes
- Control Techniques for LIMs
  - Loss minimization control 20 minutes
  - Model predictive control 20 minutes
- Sensorless Techniques for LIMs
  - Challenge and opportunity 5 minutes
  - Model reference adaptive system 5 minutes
  - Full-order Luenberger observer 5 minutes
  - Robust Kalman filter 5 minutes
- Conclusions 5 minutes

Outline (The outline shall provide a concise description of the covered topics and subtopics, omitting unnecessary details; not more than 600 words)

- Introduction on Linear Motors (LMs)
  - History and categories of LMs
  - Potential applications of LMs
- Design of LIMs
  - Key points/characteristics of LIMs
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- Parameter Estimation of LIMs
- Control Techniques for LIMs
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- Sensorless Techniques for LIMs
  - Challenge and opportunity
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  - Robust Kalman filter
- Conclusions

Motivation and Focus (Briefly explain why this topic is important for industrial IES community and outline the learning outcomes; not more than 600 words)

Various Linear machines have remarkable application prospect in more and more industrial applications, which are superior for the ability to realize the conversion of electrical energy to linear motion mechanical energy (or vice versa) directly through electromagnetic forces. However, for the special structure of cut-open magnetic circuit, large air-gap length, and half-filled slots, there are still some crucial problems to be resolved in order to acquire high performance. The tutorial aims to share the advancements in the linear machine topologies, integrated modelling, multi-objective optimization techniques, and high-performance control strategies and its emerging applications in transportation, energy conversion systems, and so on. Researchers and engineers from electrical, mechanical and information fields may find it

useful when dealing with transportation motor and drive related design, optimization and control development, mechanical design and analysis, *etc*.

Brief CV (Photo, name, email, and short CV)

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Prof. Wei Xu received the double B.E. degree from Tianjin University (TJU), China, in July 2002, and M.E. degree from TJU in March 2005, and the Ph.D. degree from Institute of Electrical Engineering, Chinese Academy of Sciences (IEECAS), in July 2008, respectively, all in electrical engineering. His research interests His research topics mainly focus on electromagnetic design and control algorithm of linear machines, permanent magnet machines, brushless doubly-fed induction machines (BDFIMs), and so on.

From 2008 to 2012, he made Postdoctoral Fellow with University of Technology Sydney, Vice Chancellor Research Fellow with Royal Melbourne Institute of Technology, Japan Science Promotion Society Invitation Fellow with Meiji University, respectively. Since 2013, he has been Full Professor with State Key Laboratory of Advanced Electromagnetic Engineering in Huazhong University of Science and Technology, China.

Prof. Xu has been one IEEE Senior Member since 2013, and one Fellow of the Institute of Engineering and Technology (IET) since 2018. Since 2014, Prof. Xu has been invited to make more than ten-time Keynote Speaking in International Conferences. Meanwhile, as one Guest Editor, Prof. Xu has been invited to organize more than ten-time Special Issues in peer review high-quality Journals, such as IEEE Transactions on Industrial Electronics. As the principle speaker, he has been invited to given five-time Tutorial about Linear Machines and Drive Systems in IEEE leading conferences, including IEEE Industrial Electronics Conference (IECON, Oct. 2018), IEEE International Conference Electrical Machines and Systems (ICEMS, Aug. 2018), International Conference on Electrical Machines (ICEM, Aug. 2020), respectively.

Prof. Xu served the General Chair for 2021 International Symposium on Linear Drives for Industry Applications (LDIA 2021) in Wuhan, China, and will serve the General Chair for 2023 IEEE International Conference on Predictive Control of Electrical Drives and Power Electronics (PRECEDE 2023) in Wuhan, China. He has been the Founding Chair for IEEE IES Wuhan Chapter since 2018. He has also been the International Steering Committee (ISC) Member for linear machines and drives. Meanwhile, Prof. Xu has been Associate Editor for several leading IEEE Transactions Journals, such as IEEE Transactions on Industrial Electronics, IEEE Transactions on Vehicular Technology, IEEE Transactions on Energy Conversion, and so on.

Prof. Xu is now leading one research group, Center for Energy Conversion System (CECS, http://machinececs.seee.hust.edu.cn/), including 6 staff and over 40 PhD/ME students, for the development on high performance of electrical machines (particularly linear machines) and drive systems based on transportation, wind generation, servo, etc. He has more than 110 papers accepted or published in IEEE Journals, two edited books published by Springer Press, one monograph published by China Machine Press, and more than 150 Invention Patents granted or in pending, all in the related fields of electrical machines and drives.

Relevant publications (* Corresponding author)

[1] **W. Xu** and Y. Liu, Advanced Control Technologies for Brushless Doubly-Fed Induction Machine, China Machine Press, May 2020. (**Book**)

[2] **W. Xu**, R. Islam, and M. Pucci, Advanced Linear Machines and Drive Systems, Springer Nature Singapore Pte Ltd., Sep. 2019. (**Book**)

[3] R. Islam, F. Rahman, and **W. Xu**, Advances in Solar Photovoltaic Power Plants, Springer-Verlag Berlin Heidelberg, Jun. 2016. (**Book**)

[4] **W. Xu**, Q. Wang*, Y. Liu, X. Li, and K. Liao, "Adaptive full-order displacement observer for sensorless resonant frequency tracking control of linear oscillatory machines," *IEEE Transactions on Industrial Electronics*, vol.69, no.2, pp. 1310-1321, Feb. 2022.

[5] **W. Xu**, X. Li*, J. Zhu, and Q. Wang, "3D modelling and testing of a stator-magnet transverse-flux linear oscillatory machine for direct compressor drive," *IEEE Transactions on Industrial Electronics*, vol.68, no.9, pp. 8474-8486, Sept. 2021.

[6] **W. Xu**, A. Junejo*, Y. Liu, M. Hussien, and J. Zhu, "An efficient anti-disturbance sliding-mode speed control method for PMSM drive systems," *IEEE Transactions on Power Electronics*, vol.36, no.6, pp.6879-6891, Jun. 2021.

[7] O. Mohammed, **W. Xu***, Y. Liu, and F. Blaabjerg, "An improved control method for standalone brushless doubly-fed induction generator under unbalanced and nonlinear loads using dual-resonant controller," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 7, pp. 5594-5605, Jul. 2021.

[8] **W. Xu**, M. Ali, S. Allam, M. Elmorshedy, and C. Mu*, "One improved sliding mode DTC for linear induction machines based on linear metro," *IEEE Transactions on Power Electronics*, vol.36, no.4, pp. 4560-4571, Apr. 2021.

[9] **W. Xu**, Y. Zhang, G. Du*, J. Zhu, and M. He, "No-load performance analysis of an asymmetric-pole single-phase doubly salient permanent magnet machine," *IEEE Transactions on Industrial Electronics*, vol.68, no.4, pp. 2907-2918, Apr. 2021.

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[13] **W. Xu**, M. Elmorshedy, Y. Liu*, J. Rodriguez, and C. Garcia, "Maximum thrust per ampere of linear induction machine based on finite-set model predictive direct thrust control," *IEEE Transactions on Power Electronics*, vol.35, no.7, pp. 7366-7378, Jul. 2020.

[14] **W. Xu**, E. Alameen, Y. Liu*, and J. Zhu, "An MRAS speed observer based on control winding flux for sensorless control of standalone BDFIGs," *IEEE Transactions on Power Electronics*, vol.35, no.7, pp. 7271-7281, Jul. 2020.

[15] **W. Xu**, K. Yu, Y. Liu*, and J. Chen, "Improved collaborative control of standalone brushless doubly-fed induction generator under unbalanced and nonlinear loads considering voltage rating of converters," *IEEE Transactions on Power Electronics*, vol.35, no.5, pp. 4959-4970, May 2020.

[16] X. Chen, **W. Xu**, Y. Liu*, R. Islam, "Bearing corrosion failure diagnosis of doubly-fed induction generator in wind turbines based on stator current analysis," *IEEE Transactions on Industrial Electronics*, vol.67, no.5, pp. 3419-3430, May 2020.

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