Discussion of "Simulation of Switched Reluctance Motor Drives Using Two-Dimensional Bicubic Spline"

H. C. Lovatt

I would like to comment on the paper by Xiang-Dang Xue *et al.*, [1]

The bicubic spline technique presented in this paper was first published in a reluctance motor context by Manzer *et al.*, [2].

Subsequently, the technique was improved upon by Stephenson and myself in [3].

Both of these older papers discuss the more difficult task of fitting to measured data that may contain noise whereas the recent publication only discusses noise-free data. The second paper, in particular, shows how data can be smoothed. For example, to see the smoothing of the fitted surface, contrast Fig. 4 in [3] with (coincidentally) Fig. 4 in [1], the latter shows spurious high-frequency ripples.

Also, the bicubic spline technique is well known in mathematical literature and available in standard math libraries (e.g., NAG).

Despite the technique being well known in mathematical literature and previously published in the context of reluctance motors, I do not wish to suggest that the authors were in anyway trying to claim the work of others as their own. I would suggest that it was simply an oversight by the authors and that the authors were not aware of either the mathematical literature or motor literature on this subject.

REFERENCES

[1] X.-D. Xue, K. W. E. Cheng, and S. L. Ho, "Simulation of switched reluctance motor drives using two-dimensional bicubic spline," *IEEE Trans. Energy Conversion*, vol. 17, pp. 471–478, Dec. 2002.

[2] D. G. Manzer, M. Varghese, and J. S. Thorp, "Variable reluctance motor characterization," *IEEE Trans. Ind. Electron.*, vol. 36, pp. 56–63, Feb. 1989.

[3] H. C. Lovatt and J. M. Stephenson, "Measurement of magnetic characteristics of switched-reluctance motors," in *Proc. Int. Conf. Electrical Machines*, Manchester, U.K., Sept. 1992, pp. 465–469.

Closure on "Simulation of Switched Reluctance Motor Drives Using Two-Dimensional Bicubic Spline"

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We thank Dr. Lovatt for his interest in the paper [1]. In the following, we attempt to answer the queries raised by him.

In fact, three publications on cubic and bicubic splines were cited in our paper. One of which is a mathematical literature [2] ([12] in the paper). The others are the references in switched reluctance motor (SRM) field [3], [4] ([2], [3] in the paper).

Without doubt, bicubic spline is mathematically a mature interpolation technique [2]. The bicubic spline function used in our paper is just based on [2]. Especially, we have pointed out in the last paragraph in Section II in our paper that detailed description of bicubic spline interpolation as seen in [2].

Spline interpolation is widely applicable to science and engineering and is a very efficient tool to precisely fit discrete data. Our paper cited two papers on cubic and bicubic splines in SRM field [3], [4]. In [3], the cubic spline was employed to represent the phase flux linkage/phase current curves for a set of discrete rotor position values. Reference [4] presented that the cubic spline is utilized to fit the experimental data of flux linkage/current and the bicubic spline interpolation is used to estimate the rotor position and the torque.

It is clear that our paper has briefly presented previous related works on bicubic spline interpolation in mathematical and SRM fields. The contribution of our paper is 1) to explore how utilizing bicubic spline technique to accurately compute the flux linkage at arbitrary rotor position and current by use of a small quantity of the known data; 2) to investigate the effect of the number and distribution of the known data on the accuracy of the flux linkage interpolation computation; and 3) to apply the bicubic spline interpolation to simulating the SRM drive.

It should be noticed that the nonlinear magnetic characteristics in SRM may be obtained from finite-element analysis or experiment on an existing motor, not only from experiment. Furthermore, no measurement noise will exist for finite-element method (FEM). Our paper is focused on accurately and rapidly computing the magnetic characteristics at arbitrary rotor position and current using the bicubic spline technique from as few as possible known data, rather than smoothing the measured data. Fig. 4 in our paper illustrates the actual interpolation results using the bicubic spline technique, based on a limited number of known data. The figure has no intention on showing the spurious high frequency ripples as Dr. Lovatt suggested. The figure only illustrates the capability of the interpolation method.

In the first paper [5] listed by Lovatt's discussion, Manzer *et al.* investigated a method of approximating the dynamic equations describing the characteristics of SRM through a least square approximation to measured flux linkage. The fitting measured data in two variables (current and rotor position) are carried out in two steps. Mathematically, fitting and interpolation are two different concepts. As for fitting methods, the fitted curve/surface may not be necessary to include the known data points. For interpolation methods, whereas all of the known data points must be on the interpolated curve/sentence. Clearly, the fitting method presented by Manzer *et al.* is different from the bicubic spline interpolation used in our paper.

In Lovatt and Stephenson's paper [6], a measurement technique was described that can accurately determine both the flux linkage and torque for an SRM. It is claimed in their paper that a bicubic spline surface fitting routine from a standard library was used to smooth the captured data. Further description on the bicubic spline was not found. It can be seen that the aim of our paper is different from the one from Lovatt and Stephenson [6]. The paper from Lovatt could have been included as the reference list of the paper; however, the coverage of the paper [6] is not bicubic spline and the circulation of the paper [6] is limited (not in IEEE Xplore); therefore, we have not cited the paper.

REFERENCES

[1] X.-D. Xue, K. W. E. Cheng, and S. L. Ho, "Simulation of switched reluctance motor drives using two-dimensional bicubic spline," *IEEE Trans. Energy Conversion*, vol. 17, pp. 471–477, Dec. 2002.

[2] H. Spaeth, *Two Dimensional Spline Interpolation Algorithms*. Wellesley, MA: A. K. Peters, 1995.

[3] D. W. J. Pulle, "New data base for switched reluctance drive simulation," in *Proc. Inst. Elect. Eng., B*, vol. 138, Nov. 1991, pp. 331–337.

[4] J. C. Moreira, "Torque ripple minimization in switched reluctance motors via bi-cubic spline interpolation," in *Proc. IEEE Power Electron. Specialists Conf.*, vol. 2, 1992, pp. 851–856.

[5] D. G. Manzer, M. Varghese, and J. S. Thorp *et al.*, "Variable reluctance motor characterization," *IEEE Trans. Ind. Electron.*, vol. 36, pp. 56–63, Feb. 1989.

[6] H. C. Lovatt and J. M. Stephenson, "Measurement of magnetic characteristics of switched-reluctance motors," in *Proc. Int. Conf. Electrical Machines*, 1992, pp. 465–469.

Discussion of "Bibliography on the Application of Induction Generators in Nonconventional Energy Systems"

H. D. Mathur

The authors [1] are to be commended for their valuable contributions in the field of induction generators applications in nonconventional energy systems. The bibliography would be of immense help to any researcher in this area. However, I feel, as indeed suggested by the authors, the following additional references may add to the value of the paper.

Finally, I would like to again express my appreciation for the excellent bibliography presented in the paper and look forward to further investigations in this extremely important area.

REFERENCES

[1] R. C. Bansal, T. S Bhatti, and D. P. Kothari, "Bibliography on the application of induction generators in nonconventional energy systems," *IEEE Trans. Energy Conversion*, vol. 18, pp. 433–439, Sept. 2003.

[2] S. A. Papathanassiou and M. P. Papadopoulos, "Simulation and control of a variable speed wind turbine equipped with double output induction generator," in *Proc. Int. Conf. Power Electronics, Motion Control, and Associated Applicat.*, Warsaw, Poland, 1994.

[3] M. Y. Utug, I. Eskandarzabeh, and H. Ince, "Modeling and output power system optimization of a wind turbine driven double output induction generator," *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 141, no. 2, pp. 33–38, 1994.

[4] P. G. Vernados, P. J. Papadopoulos, and M. G. Ioannides, "Autonomous double output induction generator with output voltage fed back to the excitation," in *Proc. IEEE NTUA Joint Int. Power Conf., Athens Power Tech.*, Athens, Greece, Sept. 5–8, 1993.

[5] Y. H. A. Rahim, "Excitation of isolated three-phase induction generator by a single capacitor," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 140, 1993, pp. 44–50.

[6] A. S. Mostafa, A. L. Mohamadein, and E. M. Rashad, "Analysis of series-connected wound-rotor self-excited induction generator," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 140, 1993, pp. 329–336.

[7] Y. H. A. Rahim, "Excitation of isolated three-phase induction generator by a single capacitor," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 140, 1993, pp. 44–50.

[8] I. Cadirci and M. Ermis, "Double-output induction generator operating at subsynchronous and supersynchronous speeds: Steady-state performance optimization and wind-energy recovery," *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 139, no. 5, pp. 429–442, 1992.

[9] A. M. Osheiba and M. A. Rehman, "Performance analysis of self-excited induction and reluctance generators," *Elect. Mach. Power Syst.*, vol. 19, pp. 477–499, 1991.

[10] N. Smith, A. Williams, A. Brown, S. Mathena, and A. Nakarmi, "Stand-alone induction generators for reliable low cost micro-hydro installations, energy and environment," in *Proc. World Renewable Energy Congr.*, Reading, MA, 1990, pp. 2904–2908.

[11] N. Elsonbaty, P. G. Holmes, M. Salama, N. P. A. Smith, and A. A. Williams, "VSCF induction generation in stand-alone micro-hydro generating systems," in *Proc. Int. Conf. Renewable Energy-Clean Power-2001*, 1993, pp. 89–94.

[12] N. Ammasagounden and M. Subbiah, "Microprocessor based voltage controller for wind-driven self-excited induction generators," *IEEE Trans. Ind. Electron.*, vol. 37, pp. 531–537, Dec. 1990.

[13] A. S. Abdel-Karim, S. A. Hassan, and S. S. Shakralla, "Power generation by wind energy systems using induction generators," in *Proc. Electrical Machines Conf.*, India, 1983, pp. 43–50.

[14] N. Sato, Y. Hayashi, and H. Umida, "A system of induction generator with static exciter and paralleled to a.c. power lines," in *Proc. IEEE/IAS Int. Semiconductor Power Converter Conf.*, Orlando, FL, 1982, pp. 295–304.

[15] M. Ermis and C. Arikan, "The modeling and analysis of a vertical axis wind turbine driven self-excited induction generator," *Proc. Inst. Elect. Eng. Conf. Future Energy Concepts*, 1981.

[16] N. G. Hingaroni and J. Slapp, "Application of induction generators and D.C. transmission links to small hydro electric plants," in *Proc. Symp. HVDC Power Transmission*, Phoenix, AZ, Mar. 24–27, 1980, pp. 273–281.

[17] A. V. Kitaev and L. N. Orlov, "On the physical mechanism of asynchronous self excitation and self oscillation," *Electr. Technol. USSR*, vol. 2, pp. 19–28, 1979.

[18] J. Debontridder, "The combination asynchronous generator-vertical axis wind turbine for small power applications," in *Proc. Int. Conf. Electrical Machines*, Paper G5/5, Brussels, Belgium, Sept. 11–13, 1978.

[19] L. Boldea, Z. X. Fu, and S. A. Nasar, "High-performance reluctance generator," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 140, 1993, pp. 124–130.

[20] A. H. Al-Bahrani and N. H. Malik, "Selection of the excitation capacitor for dynamic braking of induction machines," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 140, 1993, pp. 1–6.

[21] M. A. Abdel-Halim and C. D. Manning, "Direct phase modeling of synchronous generators," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 137, 1990, pp. 239–247.

[22] A. L. Mohamadein, Y. H. A. Rahim, and A. S. Al-Khalaf, "Steady-state performance of self-excited reluctance generators," in *Proc. Inst. Elect. Eng., Elect. Power Applicat.*, vol. 137, 1990, pp. 293–298.

Closure on "Bibliography on the Application of Induction Generators in Nonconventional Energy Systems"

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The authors would like to thank Mr. H. D. Mathur for contributions to the bibliography [1]. The authors would like to add the following additional references, which will prove useful and be of interest to the readers working in the area of application of induction generators in nonconventional energy sources.