Questionnaire-Based Discussion of Finite Element Multiphysics Simulation Software in Power Electronics

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***Abstract*—A questionnaire-based survey was carried out to determine the customers' requirements and the future expectations of multiphysics simulation software (MPSS) based on the finite element method in various applications of power electronics. For this survey, several responses was collected from MPSS users in the power electronic industry and academia. Based on the survey, the current features of MPSS are analyzed, and the recent advancements made are ascertained. Also, the drawbacks of the current MPSS offerings are discussed from academic and industrial perspectives. Different user groups have highlighted the need to significantly enhance the sophistication of MPSS. It is concluded that the current limitations to MPSS are simulation speed and accuracy and there are bottlenecks in the software interface. Some suggestions are given to overcome the current drawbacks of MPSS.**

***Index Terms*—Multiphysics simulation software, power electronics, simulation accuracy, simulation industry, software interface, simulation speed.**

I. Introduction

ADVANCES in computer-aided engineering (CAE) and the improvements in computing power in recent decades have made simulations the first and preferred choice in trying to solve a broad range of engineering problems including power electronics [1]–[3]. CAE is widely applied in the design, fabrication, and service phases of power converters and their components for modeling and simulation [4], [5], design and prototyping [6], [7], validation and evaluation [8], [9], and refinement and optimization [10]–[13]. The growing number of simulation software, the cost of the simulation package, the simulation time taken, the simulation accuracy, and the extent of sophistication in the simulation packages determine the choice of a simulation package commensurate with an engineering design problem [14]. Many simulation software packages have been developed to facilitate multidisciplinary research involving electrical, magnetic, mechanical, thermal, and fluid dynamics. Given the availability of advanced simulation packages, a number of multiphysics simulations has been done over the past few decades [15]. The use of multiphysics simulation software (MPSS) for advanced industrial applications has been demonstrated in [16] and [17], clearly showing the dependence on fast and accurate simulation models based on the finite element method (FEM). In addition, the need for closer coupling, multidiscipline analysis, multiscale modeling, and better integration with computer-aided design software is highlighted in [18] and [19]. A survey [20] has revealed that there is a significant need identified by the software users to improve the reliability monitoring methods of power electronics simulations. New techniques for high-speed real-time simulation requirements are discussed in [21]. Results produced by three software packages for reliability block diagram modeling are compared in [22]. In [22], it was hypothesized that there would be differences in the simulation results produced by different software packages owing to the differences in their algorithms and simulation methodologies, particularly for complex assemblies and multidisciplinary targets; as in the case of power electronics. The performance of MPSS could be improved from the user end too, as maintaining a reusable and organized structure of the simulation data could help in reducing the time required to model a physical problem [23].

While some of the simulation software such as Matlab, Simulink, PSpice, and PLECS focus on the analysis of electrical signals and the performance of the electric circuit, simulation software like ANSYS, Comsol, and Abaqus are utilized for solving electrical, mechanical, thermal, and other problems by using the FEM over the years. FEM-based multiphysics simulation has been gaining increasing significance in the design of components and subassemblies of a power electronics system [24]–[27]. For example, the concept of an integrated motor drive [28] is highly useful for electric vehicle applications to meet the ever-increasing demand for high power density. As shown in Fig. 1(a), a triple simulation (electrical-magneto-thermal)-based design and development of the cooling structure provides an optimized solution for thermal–mechanical integration of the electronic components within the motor housings. This saves the time and expense associated with a trial and error proce-

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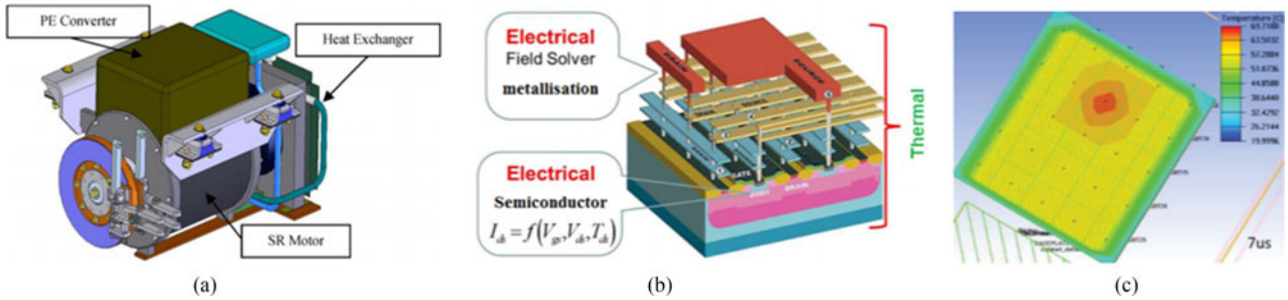

Fig. 1. Examples of multiphysics simulation in power electronics: (a) an integrated motor drive; (b) thermoelectrical model; (c) robustness under extreme conditions of power modules.

dure of physical prototyping. Another example is the coupled electrical and thermal characteristic analyses of power semiconductors and their packaging [7], as shown in Fig. 1(b), where the challenges of different time scales inherent to an individual physical domain must be addressed. A third example is the dynamic robustness studies of power devices as shown in Fig. 1(c), where the coupled electrothermal performance of power semiconductors is examined under extreme conditions by considering inherent processing-induced inhomogeneity. Hence, the use of MPSS in power electronic applications is essential and inevitable. As the questionnaire focuses on the integration of FEM-based MPSS for simulating multiphysical problems in power electronic systems, electric circuit simulation software is out of the scope of this discussion. Moreover, in MPSS packages, different solvers may be used for different domains such as electrical, thermal, fluid, etc. For example, FEM is used by ANSYS Classic and finite volume method is used by ANSYS Fluent. The choice of a solver is dependent on the physical domain, and a discussion of this is also beyond the scope of this paper.

This paper presents the key results from a web-based questionnaire responded by high-end power electronics users of MPSS. Thus far, a customer experience driven evaluation of MPSS has not been adequately studied. Many issues need to be explored, such as:

1) the tradeoff between the running cost and the credibility of multiphysics simulation;
2) training and learning needs of MPSS;
3) interaction and interoperability between different MPSS;
4) the indispensability of MPSS in power electronics.

Therefore, an investigation of the abovementioned issues is necessary and will be helpful for the development of MPSS. In this paper, a web-based questionnaire was set up to collect feedback from the users to analyze the problems with current MPSS to provide reference information to the software developers and vendors and help them to improve their products. In particular, this questionnaire survey was carried out to study the customers' attitudes and opinion about current MPSS packages, their key features, and to identify the bottlenecks with MPSS simulations. Moreover, questions are designed to obtain users suggestions for the further development of MPSS. The targeted audience of the questionnaire is MPSS users from industry and academia whose focus is power electronics and their applications.

This paper is organized as follows: Section II presents the various parts of the questionnaire and the specific questions posed. A brief description of each part of the questionnaire and the main results collated are presented in Section III. In Section IV, a discussion of the respondents' feedback, accompanied by the suggestions are provided. Finally, the conclusions are summarized in Section V.

II. Questionnaire Structure

A detailed questionnaire was designed to evaluate:

1) awareness and usage of MPSS;
2) importance of MPSS prior to practical design and implementation;
3) user's experience of MPSS in performing double or triple-physics simulations and any specific issues/problems encountered;
4) sophistication and reliability of the software in performing advanced simulations;
5) correlation between MPSS and practical results;
6) simulation-based prototyping, etc.

Some of the questions required subjective responses, while the others were objective with some requiring just multiple selection(s).

The questionnaire consists of four parts, each comprising several questions which are given below: Part 1 (Q1–Q5): Participants information and familiarity with MPSS:

1) Type of organization (Industry/Academia/Research).
2) Please name up to three MPSS packages that you are currently working with (example ANSYS, Comsol, MSC Software) (multiselection).
3) How often do you use MPSS packages?
4) What type of prior MPSS training you have had/require? (multiselection).
5) How do you judge your competence in understanding the theory of numerical methods (like FEM, FVM, BEM, meshless) used in MPSS simulators?

Part 2 (Q6–Q12): Experience with MPSS:

6) What type of double-physics coupling simulation are you using or have worked with? (multiselection).
7) What type of triple-physics coupling simulation are you using or have worked with? (Please type words example Electrical—Thermal—Mechanical, or None).
8) Which of the following computation stages takes the longest time in your multiphysics simulation? (multiselection).

9) What type(s) of multiphysics simulation have you done? (multiselection).
10) What type of coupling level have you used in your multiphysics simulation? (multiselection).
11) Is extra programming/scripting needed to perform your multiphysics simulation? If yes, rate the difficulty in programming?
12) What kind of methods do you generally use to improve the convergence of multiphysics simulation? (multiselection).

Part 3 (Q13–Q19): Evaluation of MPSS:

13) To what extent do you agree that multiphysics simulation is currently too slow and computationally intensive?
14) To what extent do you agree that multiphysics simulation is more accurate for complex problem solving than multiple single-physics simulations?
15) Have you ever given up multiphysics simulations because it was too complicated to use, slow or for any other reason?
16) To what extent do you agree that current multiphysics simulations can help us to solve the problems in your industry/research?
17) Which of the following aspects you think should be improved to resolve the current bottlenecks with multiphysics simulations? (multiselection).
18) To what extent do you agree that a lack of benchmark experiments/validation data restricts the popularity of multiphysics simulations?
19) How do you rate the importance of multiphysics optimization to your work?

Part 4 (Q20–Q25): Issues with and future of MPSS:

20) To what extent do you agree that a triple-physics simulation software package will yield better design results compared to double-physics software?
21) How often have you been unsatisfied with the simulation results based on your multiphysics model any disagreement between MPSS and practical results?
22) In your experience, why do you think there is a mismatch between multiphysics models and experiment?
23) To what extent do you agree that system-level simulation containing at least triple physics is a must for your future work?
24) What types of physical effects would you like to visualize and suggest inclusion in MPSS for advanced modeling and analysis (for example, thermal model on boundary conditions between rotor of machine and air, temperature-dependent parasitic effects)?
25) Please provide any suggestions or comments for the future development of MPSS.

III. Results

This research was carried out using a web-based questionnaire, which has been conducted for 10 months and was completed in November 2016. About 2856 people have been contacted. Contact details were established by using a web-based search to identify industries working in the field of power electronics. First, websites such as Center for Power Electronics Systems (https://cpes.vt.edu), Ventureradar (https://www.ventureradar.com), European Centre for Power Electronics (http://www.ecpe.org/), and Global Companies (http://www.companiess.com/) listing power electronics companies, network organizations and vendors have been used to establish contacts in industry and academia. Second, a Google search was conducted to find additional company names, academic institutions, and organizations that were not listed in the previous search. From the 2856 contacted, 33% are from industry, 4% are vendors, 17% are industrial-based research centers (e.g., Fraunhofer Institute) and 46% are from academia. Depending on the search criteria and the size of the company/organization, our data show that there is either one contact per company/organization or multiple contacts per company/organisation. All contacts have been invited during the same time via email asking them to take part in the online survey. Reminders were sent twice. The above activities resulted in 82 effective responses. The sample number 82 can be regarded as a good representation of the overall population and falls within the limits of effective responses obtained in the other surveys which have been published in other journals. For example, Yang *et al.* [20] lists 67 effective responses representing the global power electronics industry, Chiou *et al.* [29] has 124 effective responses representing the whole industry of Taiwan, and [30] reports 83 effective responses representing many multinational companies on a global scale.

TABLE I
Respondent Sector Statistics

Respondent sectors	Number
Research/academic organisation	41
Industry R&D department	27
Industrial-based research center	4
Software developer or vender	4
OEM & supplier	2
Others	4

All the respondents and their affiliations are concealed to comply with the nonpublic disclosure of business information.

A. *Characterization of Respondents, Frequency of Use, Software Training, and Familiarity*

As shown in Table I, the respondents were classified into six categories through Question 1: Research/academic organization, industrial R&D, industrial-based research centers, software developer or vendor, OEM & supplier, and others. Table I shows that 45% of the effective respondents are working in the field of industrial-based problems whereas 50% work in the field of academic-based problems. Considering that many universities are working with industries, the survey can be deemed to provide an acceptable split between nonindustrial-based simulation work and industrial-based simulation work. Fig. 2 categorizes the respondents based on their work and/or their research interests, showing that most of the survey respondents are directly involved in problems related to power electronic systems, electric drives, and electronics. Each category contains a balanced number of responses from both academic and industrial backgrounds. The responses provided for Question 2 highlight the popularity of different MPSS. Fig. 3 shows that Ansys, Abaqus,

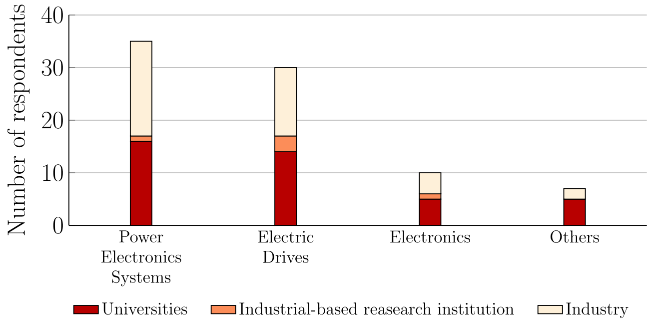

Fig. 2. Profile of survey's respondents.

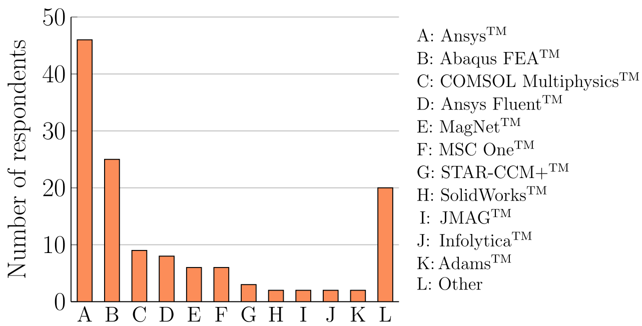

Fig. 3. Usage of different MPSS (Q2).

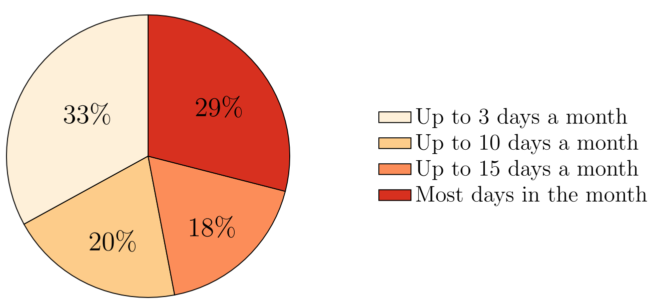

Fig. 4. User frequency (Q3).

and Comsol are the three most widely used MPSS, with Ansys being the most popular among the three. All these MPSS have the flexibility of pre- and postprocessing, user-friendly interfaces, capability to deal with multiphysics problems, and feature powerful solvers. For instance, Ansys could analyze the electrical, thermal, and mechanical issues simultaneously while performing the fatigue analysis of power semiconductor modules. In Fig. 3, the total number of responses is more than 82 since this question had multiselection answers, as indicated in Section II. It should be noted that the same applies to all the figures showing the results from multiselection questions.

The user frequency distribution of MPSS is shown in Fig. 4. The results show that a large percentage of the respondents use MPSS almost every day (29%), and about 38% use MPSS every 10 to 15 days. It can be inferred that 67% of the respondents are frequent users of MPSS. However, the responses received for the posterior questions show that there is no correlation between user expertise and usage frequency.

Questions 4 and 5 examine the software training needs, and the responses received are portrayed through Figs. 5 and

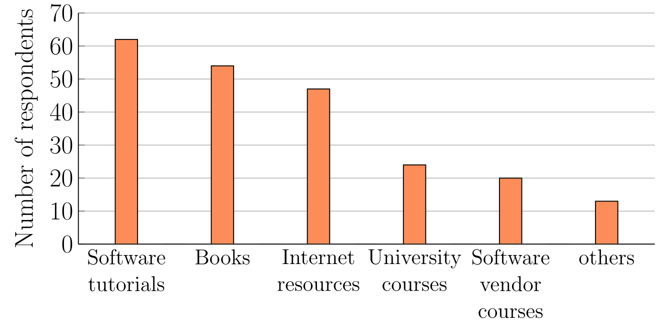

Fig. 5. Learning resources (Q4).

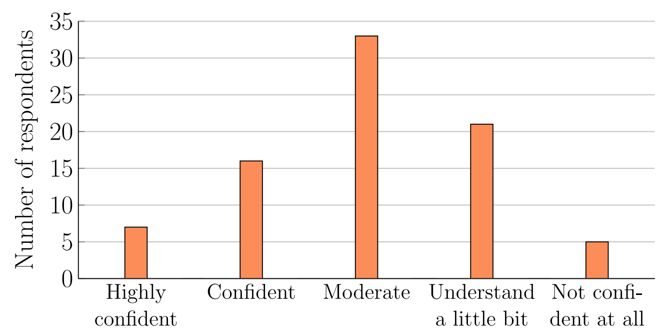

Fig. 6. Acquaintance with MPSS software (Q5).

6. It was observed that software tutorials/user manuals are more preferred than any other resource such as text books, information sourced through the internet, and any university course materials to become familiar with the fundamental and/or advanced usage of the software. Books have been used mainly to gain an understanding of the technical concepts underlying the MPSS. Given that substantial resources are publicly available in the form of software tutorials, white papers, technical/application notes, and open-access literature, more than 74% of the respondents have indicated a preference for self-learning at their own pace. Some respondents, however, have expressed interest in attending technical workshops to gain initial know-how and/or to fine-tune their design skills. This may be because MPSS is multidisciplinary, nontrivial, and hence instructor-led training could help to smooth down a steep learning curve. A minority of the respondents have indicated a keenness in attending relevant MPSS user group conferences/workshops to share their experiences and to enhance their knowledge of advanced modeling and simulation. It is revealed from the survey that to increase the acceptability and popularity of MPSS in different engineering domains, technical support should be provided in an efficient and focused manner.

B. Evaluation of Current MPSS

Questions 13 and 15 evaluated the current MPSS scenario in terms of simulation speed and computational complexity. The results are captured in Figs. 7 and 8, respectively. About 63% of the respondents reported that the simulation speed of current MPSS is too slow and is computationally expensive to achieve an optimum expectation. About 78% of the respondents admit to regularly or occasionally giving up the MPSS due to

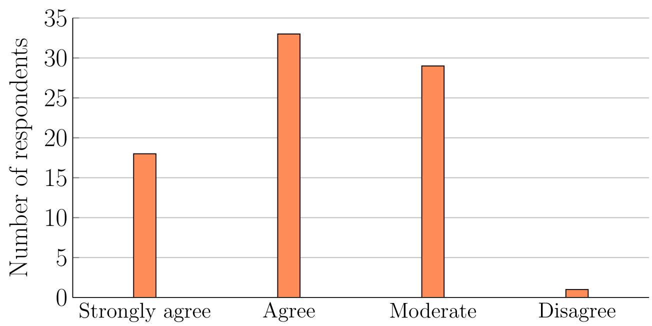

Fig. 7. Users' experience of slow running speed of MPSS (Q13).

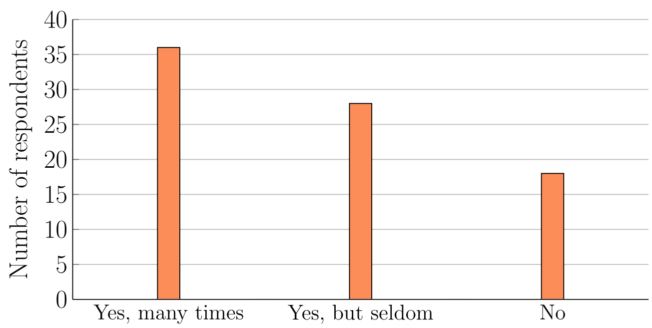

Fig. 8. Respondents giving up MPSS (Q15).

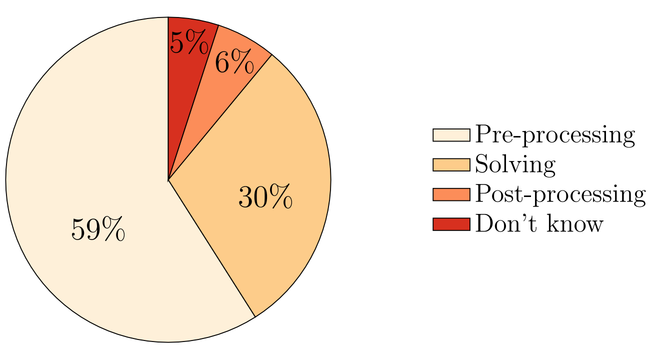

Fig. 9. Opinion about the most time consuming computational stage (Q8).

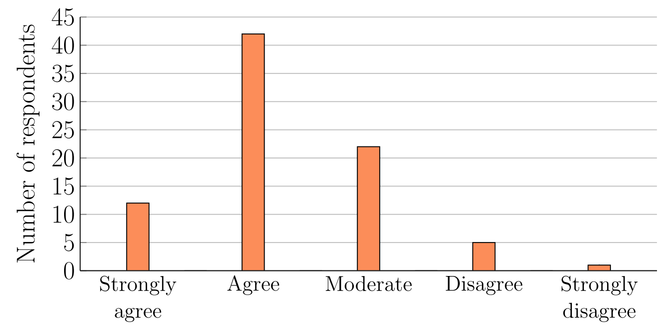

Fig. 10. Accuracy of MPSS results compared with multiple use of individual single physics software results (Q14).

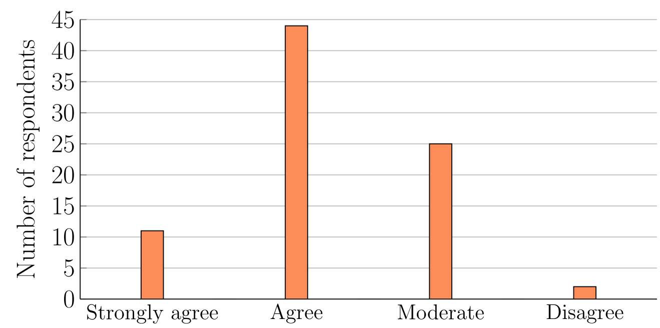

Fig. 11. Importance of MPSS for industrial applications (Q16).

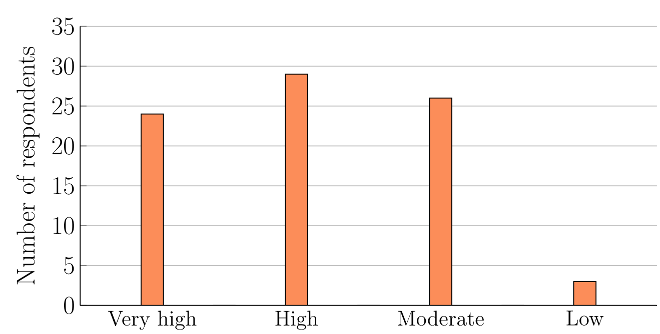

Fig. 12. Expression about inevitability of MPSS in engineering optimisation (Q19).

poor simulation speed, especially when performing complicated simulations.

The opinion of the respondents regarding the time complexity of different computational aspects of MPSS is shown in Fig. 9. Preprocessing reportedly consumes the maximum time during MPSS simulations, followed closely by the time taken by solvers. This coincides with a survey outcome of Sandia National Labs reporting that preprocessing usually consumes about 73% of the total simulation time for general applications [31]. Regardless of the software used, preprocessing generally includes geometry modeling, meshing, and setting up of boundary and initial conditions and mesh independence analysis, where meshing and mesh independence analysis take a long time especially for high-fidelity simulations. Moreover, the specification of initial/boundary conditions requires the user to have a significant multidisciplinary knowledge and engineering experience. Despite issues with the simulation time, nearly 66% of the respondents agree that MPSS provides higher accuracy than using multiple individual single physics software for complex problem solving, as shown in Fig. 10.

Questions 16, 19, 21 evaluate the importance of MPSS for industrial applications, and the corresponding responses are presented in Figs. 11–13. About 67% of the respondents believe that MPSS can solve their industrial problems, while almost 65% felt that multiphysics optimization plays a vital role in their engineering domains. Further, 55% of them convey that triple-plus physics simulation is indispensable for the future as more and more users have realized that power electronics is a multiphysics strongly coupled problem. These results signify that MPSS has a tremendous scope in tomorrow's engineering and technology. Hence, advancement of the fundamental the-

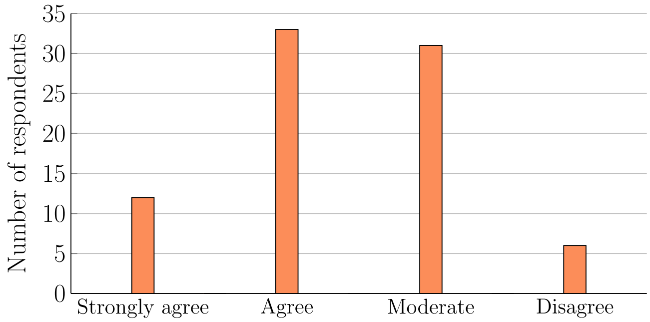

Fig. 13. Prediction about future needs of triple-physics simulation software (Q23).

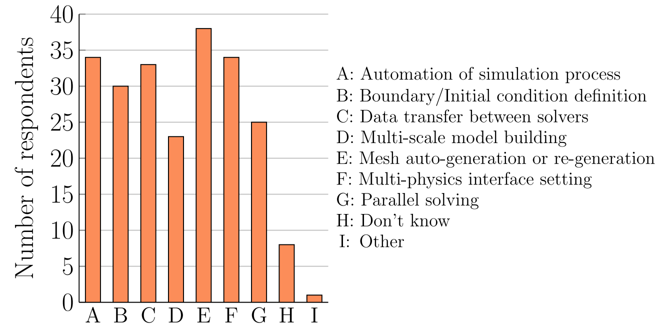

Fig. 16. Suggestions given by users for improving MPSS (Q17).

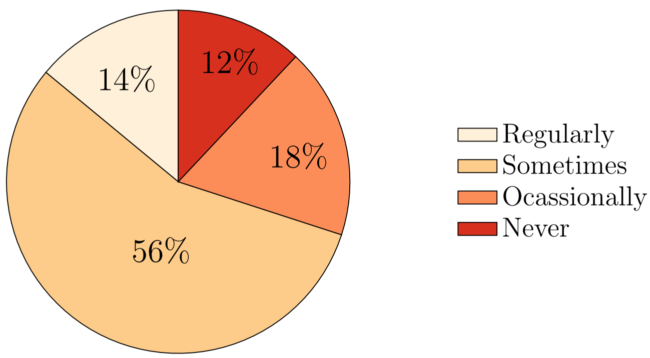

Fig. 14. User experience of differences between simulation and experimental results (Q21).

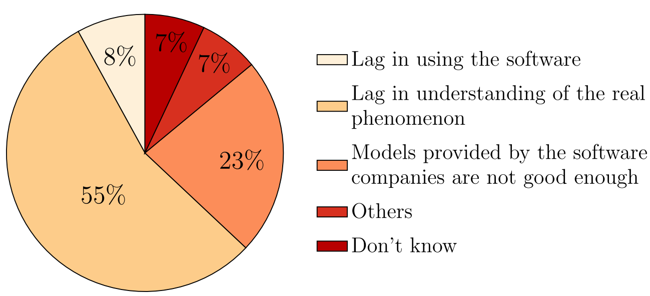

Fig. 15. Reasons given for mismatch between simulations and experimental results (Q22).

ory and the development of a user-friendly software demands immediate attention.

C. Improvements Suggested for MPSS

To explore the usefulness of MPSS in real-time applications, this survey also included questions (Questions 21 and 22) to analyze any technical deficiencies of current MPSS packages. Fig. 14 confirms that although generally good, the virtual prototype fidelity and dependability still receive common user concerns, which make physical prototype testing an inevitable verification process for CAE tools. The major reasons for this are attributed to a lack of comprehension of real-world phenomena and the varying level of fidelity in simulation models, as depicted in Fig. 15. Hence, it is felt that industry-standard models should be provided as part of a MPSS package to pave the way for better results, which would mimic or be in close agreement with experimental results.

Further, this survey has identified several areas for improvement to enhance the efficacy of MPSS packages, which are shown in Fig. 16. Mesh autogeneration or regeneration is the most popular method for FEM analysis, used in almost all MPSS. Different polyhedron generation rules have different running times, and are associated with different computational complexities. Hence, this requires attention and improvement to reduce the overall time taken by MPSS for simulations. Another important focus area is the data transfer between the solvers, i.e., ensuring an efficient interoperability among different solvers viz. fluid, solid, and electromagnetic solvers. These solvers may be designed to adopt uniform data standards and a high-quality data exchange should be guaranteed. Automation of different simulation processes is suggested as the third most important area requiring further improvement. Intelligent simulation and processing using sophisticated physical models, which do not require any manual intervention in providing specifications at any intermediate simulation stage is an important feature expected in MPSS. Multiphysics interface setting and multiscales model building are also suggested as areas for further improvement, though they are challenging and involve complex physical disciplines. Overall, the respondents' expectations on future MPSS developments are indeed significant in terms of providing powerful, faster, and comprehensive features.

IV. Discussion

The correlations between the questionnaire's questions are analyzed in this section to study the interrelationship between different respondent categories, and to discuss the results obtained through this survey.

A. Investigation of Multiphysics Processes

Fig. 17 shows that most of the users have experience with performing single- or double-physics simulations rather than triple-physics simulations, and most users are familiar in applying their single- and double-physics software tool to either single-physics problems or double-physics problems. Users provide two reasons for this:

1) single or double-physics simulation tools are usually considered to be adequate for general design and/or analysis of power electronics;

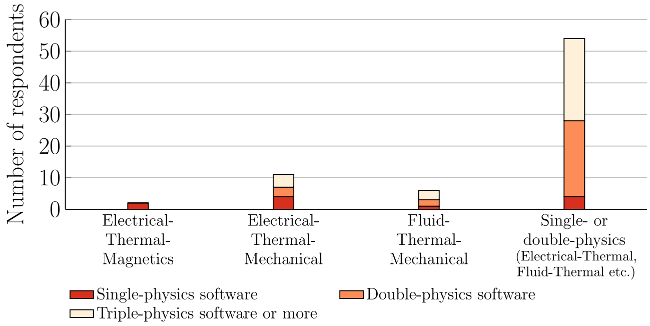

Fig. 17. Preference for single-physics and multiphysics simulations using MPSS (Q6 and Q7).

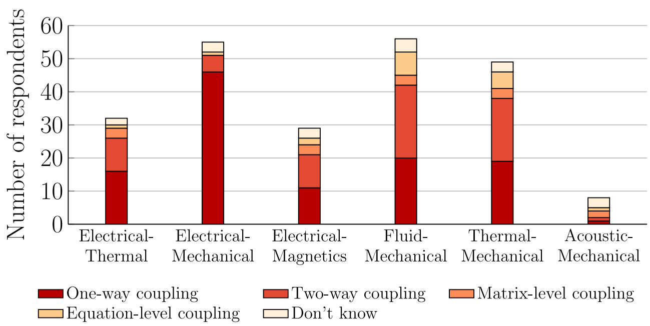

Fig. 18. Used coupling level for double-physics simulations (Q10).

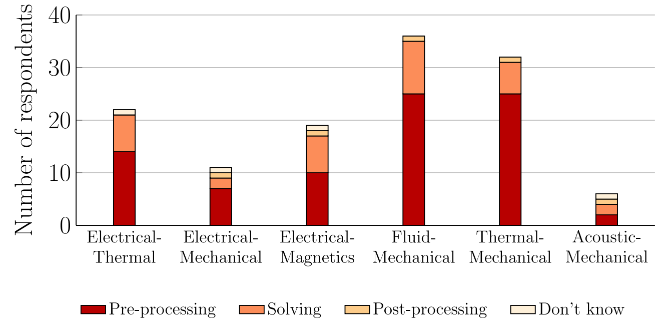

Fig. 19. Inherent computational aspects for double-physics simulations (Q8).

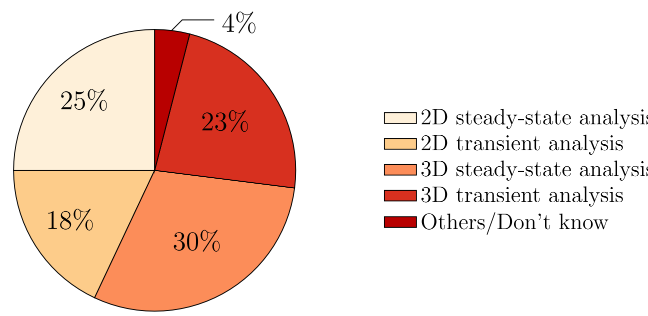

Fig. 20. Type of multiphysics simulation used (Q9).

2) the existing triple-physics software is too complicated and time consuming for general users and therefore deemed as not good enough to carry out triple-physics problems.

Consequently, if users face triple-physics problems, they end up using three single-physics simulation software packages or one single-physics and one double-physics simulation software tool. However, as the demand for high-performance power electronics increases, a triple or multiphysics simulation environment simultaneously considering electrical, thermal, magnetic, mechanical, and other physical domain(s) will be certainly required for the design and/or analysis of power electronic devices/circuits/systems in the future.

To evaluate the performance of MPSS in different double-physics simulation conditions, the correlation of dimensionality, coupling level, and simulation processing steps has been studied. The results of this analysis are shown in Figs. 18 and 19. From Fig. 18, it is seen that one-way and two-way coupling are predominantly used in double-physics MPSS. One-way coupling implies that the calculation results generated from one solver is passed on to the next solver in a straightforward manner. On the other hand, two-way coupling involves a two-way interaction and exchange of data between the two solvers for mutual processing. This can be realized by fully coupled (monolithic) approach or weakly coupled (partitioned) approach. The former one requires specialized codes and is rather slow though it is relatively accurate as it solves the multiphysics equations simultaneously. The latter one is simple, popular, and applies a separate coupling scheme by using standard solvers for each physics, yet it is slow as it performs many iterations before achieving the demanded accuracy irrespective of which coupling scheme (implicit or explicit) is used. A promising approach is to take advantage of each schemes merit and to use a so-called high-order implicit–explicit scheme to obtain high-order accuracy without coupled solvers or iterations [32]. In contrary, equation-level and matrix-level couplings do not need to transfer data between two solvers; they are designed to solve problems based on a set of combined equations and matrices, respectively. They are more accurate and faster in theory, but are only suitable for acoustic-cum-mechanical applications at present. Fig. 19 shows the users reporting preprocessing as the most computationally intensive task in a MPSS. This is mainly due to the redefining of mesh-generation/regeneration and the setting up or changing of the boundary conditions. Observing the participants' experience of multiphysics simulations, about 55% of the respondents prefer 3-D multiphysics simulation and approximately 41% prefer 2-D multiphysics simulation, as shown in Fig. 20. This may be because 3-D simulations are more sophisticated and hence useful for achieving a reliable and robust design before the prototyping and test. With respect to both 2-D and 3-D multiphysics simulations, the steady-state analysis is more preferred over transient analysis. It is important to define suitable and appropriate boundary and initial conditions for achieving a desired simulation speed as well as to quickly achieve the convergence. Most of the respondents agreed that simplifying the model and boundary conditions would ramp up the simulation speed as shown in Fig. 21. Some of them suggested that refining the mesh and adjustment of the simulation time-step could also help in improving the simulation speed. However, almost all the users have emphasized the need for powerful mesh auto/regeneration programs and the simplification of boundary condition specifications in MPSS without compromising on the simulation accuracy. Another concern addressed by the users is the unexpected delays in preprocessing followed by the solving process, as highlighted

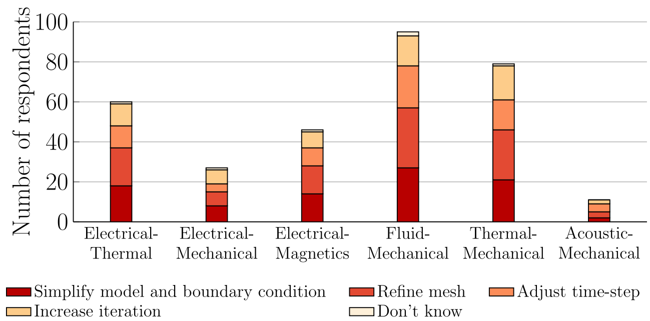

Fig. 21. Correlation between programming/scripting and time consuming computational aspects in MPSS simulations (Q11).

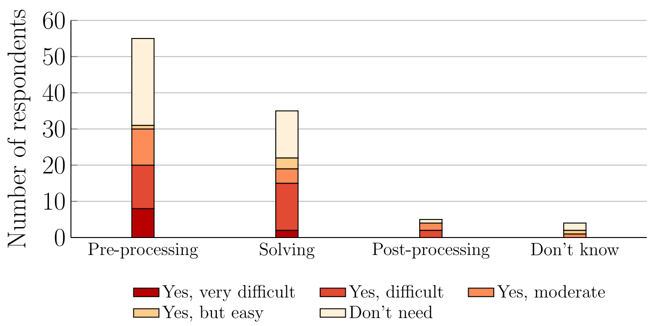

Fig. 22. Correlation between programming/scripting and time consuming computational aspects in MPSS simulations (Q11).

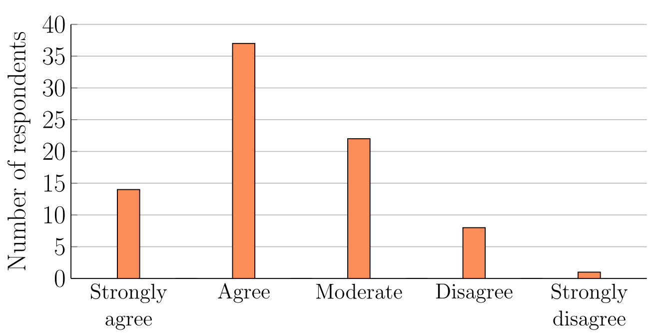

Fig. 23. Users' opinion on the advantage of triple-physics simulation compared to double-physics for achieving a better design result.

in Fig. 22. A user-defined programming/scripting is considered as a necessary and handy tool in favor of functions such as batch processing or process management. This, however, was found to be a difficult part while using MPSS, as the users are generally not proficient in coding. Moreover, the users report that the lack of a universal platform-independent programming language is a major problem with existing MPSS packages. As Fig. 23 shows, while asked to choose between a triple-physics and a double-physics simulation software based on which would yield better design results, about 62% of the participants agreed that a triple-physics simulation software package is better than a double-physics software. About 27% of the participants gave a neutral response while the remaining 11% indicated that double-physics results could be better over triple-physics simulations.

Although the performances of MPSS packages are continuously being improved, a disagreement between the MPSS

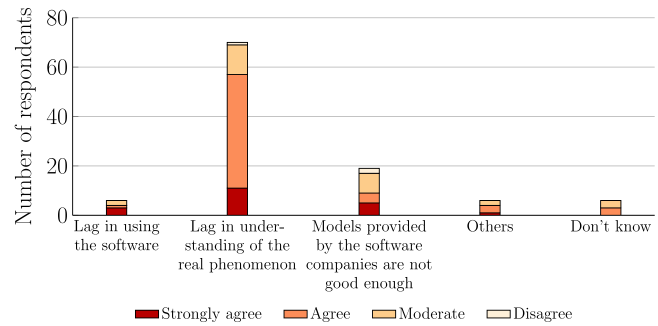

Fig. 24. Users' perception in understanding the mismatch between simulation and experimental results (Q22).

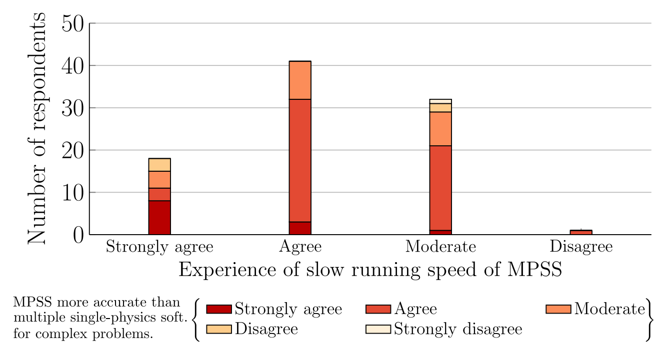

Fig. 25. MPSS accuracy versus the accuracy by using individual multiple single physics simulation at the expense of extra computational time (Q13 and Q14).

simulation results and experimental results is experienced, as portrayed by Fig. 24. While some of the users attribute this to a lack of realistic physical models in the MPSS, others reason that a mismatch between the simulation and practical results is also likely owing to poor user-defined models or due to the specification of less sophisticated (inadequately defined) models in order to cut down the simulation time. Hence, it is observed that there is a greater need for incorporating accurate physical models in the MPSS package to facilitate a good correlation between the simulation and experimental results. This will also help to reduce the number of iterations and the overall simulation time. This will in turn lead to an increase of users reliability on MPSS and would help to increase their confidence in using the MPSS.

At present, difficulties exist in developing realistic models that faithfully represent a practical system operation. This is due to the merger of multiple physical disciplines and their complex interaction, which is nontrivial to capture holistically. Moreover, there is a tradeoff between simulation fidelity and computational cost. The responses shown in Fig. 25 indicate that most of the users tend to prefer multiphysics simulations for solving complex problems, even at the expense of increased computational time, compared to performing multiple single-physics simulations in isolation.

B. *Software Improvement and Future Trend*

With respect to advanced modeling and analysis using MPSS, some of the survey participants mentioned that they would like

TABLE II
CURRENT MPSS LIMITATIONS AND PROPOSED IMPROVEMENTS

MPSS Limitations	Improvement
The simulation is slow and computationally expensive.	Automatic data transfer between different solvers. Boundary/initial conditions definition.
Some of the software do not support parallel solving.	Multiphysics interface settings. Ability to execute parallel solving.
Pre-processing is manual and cumbersome taking much time.	Mesh autogeneration or regeneration.
The simulation process and multi-physics interface setting are not user-friendly.	Automation of the simulation process. Access to relevant MPSS tutorials.
Difficulty for inexperienced and novice users to familiarize with the software.	Generation of a central database that contains benchmark models and examples. Access to tutorials, software demonstrations, interactive software training, etc. Use of a universal programming language for various MPSS.

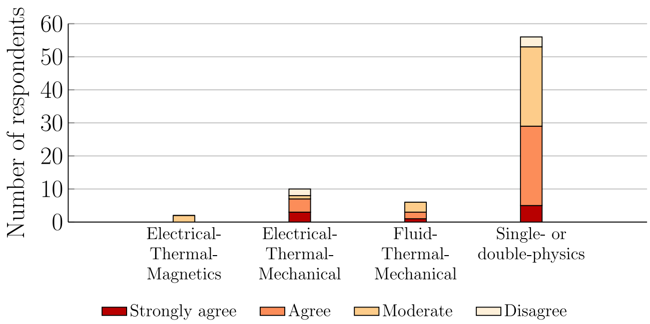

Fig. 26. Users' opinion regarding the importance of triple-physics simulations for future work (Q23).

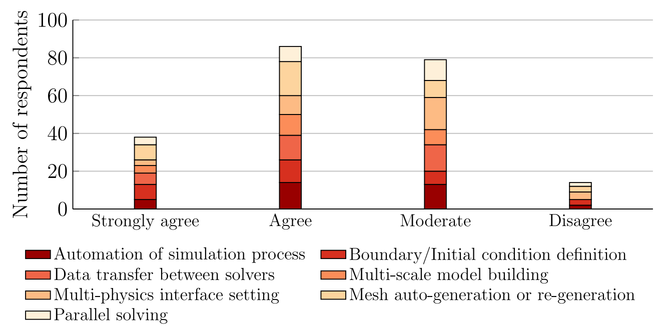

Fig. 27. Suggestions given by users to improve the performance of MPSS (Q17).

to visualize the internal stress of the linking material used for stacking the power electronic devices. Some conveyed their interest in analyzing the thermal and electrical characteristics; in particular, the comparison of thermal distribution when subject to different cooling methods, and the temperature distribution of the operating modules. A considerable number of users have specified the need for multiphysics simulations spanning different domains such as electrical, thermal, mechanical, magnetics, fluid dynamics, etc., as shown in Fig. 26. Moreover, most of the users working on single- or double-physics problems believe that triple-physics simulations will be necessary for the future. Fig. 27 shows a list of technical suggestions provided by the users to improve the efficiency of MPSS software. Multiphysics data specification, seamless data transition between the solvers (interoperability of different solvers), and the automation of intermediate simulation processes are highlighted as major areas for improvement. These three aspects tend to significantly impact the simulation time and accuracy. Improvements in virtual reality for the efficient rendering of physical components, and improvements in visualizing triple-physics graphics (high-definition portrayal) are suggested. Further, improvements in the user interface are also suggested for ease of simulations. Almost all the users widely agree that a fully automated MPSS is helpful to improve the overall simulation experience. Some of the respondents have additionally suggested that the provision of a software demonstration through a CD or online resource would help the novices or less-competent users to overcome the hurdles they may face in using the MPSS, and might motivate them to prefer MPSS regularly for their work. Table II lists all the shortcomings of the current MPSS as well as the suggestions for overcoming them to provide guidance for evolving the current MPSS, which can be utilized for developing a more comprehensive modeling and design simulation framework.

Two subjective questions were also asked at the end of the survey questionnaire. The answers provided highlight the need for the provision of sample real-time case studies along with the software, as one user stated, "What is required is a database of relevant experimental validation cases, ideally compared with numerical techniques, with which future simulations can be benchmarked. This would be particularly useful for new, inexperienced users." Several users have endorsed the need for providing industry-standard template models. Template models can help the users to further their understanding, thereby enabling them to perform better simulations with reduced modeling effort. Also, the provision of template models make the users' job easier, especially when models should be developed commensurate with an application where the in-built template models would serve as a useful reference. Moreover, if the template models are parametrizable, it would greatly benefit the users in initial specifications and would help us to reduce the simulation time and improve the simulation accuracy. The survey participants opined that simulation speed is a major concern in the system design and performance analysis using MPSS, as one user commented, "A time consuming problem must be solved through parallel computation or any other parallelization technique. Specifying of boundary conditions are not easy." To address this, although powerful and advanced solvers have been developed recently to efficiently solve nonlinear partial differential equations, which is often used in modeling [18], the overall simulation speed is still less. Hence, the interface to a multicore simulation environment, where the computationally intensive tasks can be divided and processed in parallel using several cores is highlighted as an area demanding attention to enable faster MPSS simulations. Another respondent stated, "Paying more attention on producing a more powerful solver can reduce the inconvenience in using MPSS," As mentioned earlier, the interoperability is an important feature which should be addressed in MPSS. A universal data format can significantly improve the data exchange between different solvers and eventually enhance the simulation speed. Similar observations have been recorded in [33] and [34]. It is inevitable in the coming future that more and more physics will be combined for simulation-based synthesis of power electronics. To accelerate the simulation speed, advanced preprocessing architecture and a solver architecture such as reduced-order modeling, cloud computing, and multiuser framework should be put forward and/or improved. To conclude, the opinion expressed by a respondent is given here: "A fundamental requirement for computer simulations is to accurately reflect real situations. Multiphysics software is a tool for connecting theoretical expressions with practical cases. Hence, attention has to be paid to provide smart solutions which reflect reality." This statement further emphasizes the need for accuracy and reliability of MPSS simulations in power electronics.

V. Conclusion

This paper has analyzed the present scenario and future trends of finite element MPSS with respect to power electronics using a web-based questionnaire. The questions are designed from the perspective of current MPSS users and from their responses, the reasons for the limited use of MPSS are deciphered. Although many users have agreed that multiphysics simulation is indispensable for the future, it is inferred that the current bottlenecks with MPSS simulations are simulation speed, simulation accuracy, credibility of simulation results vis–vis experimentation, interoperability within MPSS, portability between different MPSS packages, nonavailability of industry-standard physical models, lack of a platform-independent scripting/programming language, no support for parallelism, and software training needs. Hence, this paper, besides highlighting the challenges faced by MPSS, makes an important contribution to influence the direction of future research and development of FEM-based MPSS packages. In the future, another web-based survey is planned to capture how finite element software developers have addressed users concerns and to measure the impact of the new developed tools.

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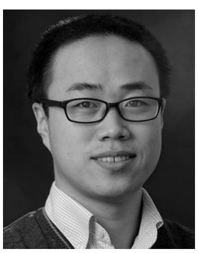

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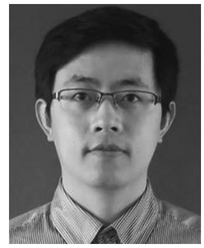

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