The Journey of a Young Transformer Designer: The Future of the Industry

by **Curtus Duff**

Curtus Duff is an Electrical Design Engineer at SPX Transformer Solutions where he designs medium and large power transformers. He graduated from Purdue University in 2016 with a Bachelor of Science in Electrical Engineering. Upon graduation he started at SPX Transformer Solutions in the Engineering Development Program with six-month rotations each in Design, Testing, Manufacturing, and Application Engineering. Upon completion of the program in 2018, he joined the design team. He is located in Waukesha, Wisconsin where he enjoys the outdoors in activities such as mountain biking and skiing.

Foreword from the Editor in Chief

When I first met Curtus, I thought about how young he was and how much tribal knowledge her could gain from people in the industry. Over tacos in Texas, and you can't say that often enough, Curtus and I talked about his learning track to the future. This article is his journey on the track. I cannot thank him enough for his contribution to our community. Curtus is one of the rising stars of our industry and one someone I am delighted to add as a Contributing Editor. Enjoy!

Photo: SPX Transformer Solutions

Young engineers are eager to learn. Take a young engineer and put him or her in the right environment, and learning will happen.

The power industry currently is that "right environment," due to its relatively older work force, ripe with experience and knowledge ready to be shared.

I have heard many conversations about plans for retirement, such as fishing or moving to Florida, or both. When the masters of the industry decide to move to Florida, they take their tribal knowledge with them. Now is the time for young engineers to download as much of that knowledge as they can from seasoned engineers. Now is the time for seasoned engineers to teach them. I write this article to take the reader through my own experience as a transformer designer. Many transformer designers will likely share a similar experience. I will go through my story, my process of learning, and explain how I have realized that a culture of passing down tribal knowledge is the key for future success.

During university, I would ask myself, "How much of this stuff am I actually going to use when I get out into the real world?" I jumped all too fast to the conclusion: probably not that much. I was wrong. I recently had a conversation about this topic with a colleague, Doug Reed, a principle design engineer at SPX Transformer Solutions. He told me an interesting story about a time when he had a reunion with some of his college friends. They talked about what they do for a living and about how much of their college education they use in their careers. Doug calls it his "bragging rights" when he makes claims about how much of his college education he actually calls upon when designing transformers. When Doug started listing off his classes, I realized he was onto something. The relevance is quite astounding when you actually think about it!

Here is my list of engineering classes applicable to transformer design:

- Thermodynamics - Cooling
- Statics - Clamping and Tank Structure
- Circuit Analysis - RLC Properties
- Electromagnetics - Flux and Harmonics
- Fields - Magnetic Fields and Dielectric
- Physics - Short Circuit Forces and Winding Strength
- Materials Science - Steel, Oil, Copper, Paper
- Mechanics of Materials - Material strength
- Fluid Dynamics – Flow of Cooling Liquids and Air

Not including the sadistic engineer that takes all of these classes and triple majors in Electrical Engineering, Mechanical Engineering, and Physics, most engineers will take a good percentage of these classes.
I personally took the ones my degree required. In my electromagnetics course, we covered transformers for all of one chapter, with a description of a standard, ideal, single-phase transformer as the main takeaway - primary on the left leg and secondary on the right leg. While this was great information for an entry-level position interview, in no way was this information enough to become a good transformer designer.

The point of university was not to teach me exactly what I needed to know in order to be a transformer designer. Instead, my education was meant to be a foundation. While university is certainly not the only way to achieve a solid foundation, going through the brainstorming exercise with Doug made me realize how great of a foundation university was for me. I was challenged daily, and the classes I took taught me how best to learn. For both, I am forever grateful. Exploring transformer design is like staring through the skinny part of a very wide and very tall traffic cone. The deeper you look, the more opportunities surface to learn. The ability to learn is what guides engineers to travel through this metaphorical traffic cone successfully. Every day that passes is another day to learn something new.

Photo: SPX Transformer Solutions

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Day one of employment in the summer of 2016 began my own exploration through SPX Transformer Solutions's traffic cone of knowledge.

In reality, we orient the primary and secondary windings concentrically. I guess the one chapter discussing transformers in school was not exactly perfect! A new engineer starts out by meeting everyone, exploring the plant, and spending time on weekly learning goals. For me, this learning objective started with reading about Michael Faraday; deriving the volts per turn equation; learning about load loss, core loss, flux density, leakage flux, percent impedance, basic insulation levels, winding types, manufacturing processes, and testing requirements. After the first week, the task ahead of me seemed quite daunting and overwhelming. As I ventured further into the giant traffic cone, the sheer volume of what I did not yet know appeared to be getting bigger and bigger. The light at the end of the...cone seemed so far away. I spent what felt like decades going through internal engineering documentation, vital components to learning the steps of designing and having a central location of company knowledge. These documents are literally a collection of knowledge handed down by many engineers before me. After weeks of training, asking "what is this?" on the shop floor, reading text book after text book, digging through engineering instructions, and examining the details of customer specifications, eventually my boss graced me with the opportunity to fulfill my destiny. By fulfill my destiny, I actually mean my boss said, "Let's start you off with a mock design."

One can read a book about swimming, but that is not going to be enough training to jump into the deep end of a pool. A mock design was essentially me starting to learn to swim in the shallow end. Although I was a little disappointed, because I wanted to make a real contribution to the team, a mock design alleviated the pressure and allowed me to practice designing with no consequences. This would allow me to learn by doing. While all the self-study to get to this point was important, most of the opportunities for learning came about by actually designing a transformer.

The process started with the task of going through records and finding a unit the company built before that was not too challenging. This way I could pretend I was the original designer, and afterwards, have a design to compare to my own. The unit I was looking for was a 69 kV to 12.47 kV delta-wye transformer with a de-energized tap changer. Something like this typically has a basic insulation level of 350 kV on the high voltage side, 110 kV on the low voltage side and a percent impedance of 8%. I found one with a base rating of 15 MVA and a max of 28 MVA at 65°C degree rise. This was simple enough to get started and perfect for my mock design.

The key to designing a transformer is optimization. My studies had gotten me to the point of understanding the relationships between design and performance. For example, how volts per turn can affect flux density and, therefore, core size. How winding cable geometry can affect stray losses and impedance. How oil flow can affect cooling performance. How insulation design can affect dielectric withstand. How cable dimensions can affect the ability to withstand short circuit forces. The list of design to performance relationships is a long one! The challenge of these many relationships is that they are intermingled. As one design attribute is changed to get a desired outcome, another desirable outcome suffers. Dielectric changes can trade off with cooling performance, while tweaking impedance can trade off with losses. The list of design tradeoffs is also long. Talk to any transformer designer, and they could bore you to death with the tradeoffs. If these design relationships and tradeoffs were not confining enough, they also affect the total cost in a variety of quantities. In many cases, cost is arguably the most important factor for the customer.

Even so, the biggest constraint of them all is that the final design needs to be manufacturable. A designer cannot just do whatever he or she wants. The plant's future manufacturing experience must be considered during the design process. Designing a transformer is the ultimate balancing act. A good designer is one who can optimize amongst all of the variables at play to end up with a design the customer was looking for at the right price. This is exactly what I was trying to achieve with my mock design.

The perfectly optimized design is accomplished through an iterative process. Once I got to where I felt comfortable with my optimized mock design, I ran it through simulation software. Running a model of the design through simulation software is important to prove that the transformer is meeting all performance characteristics, such as losses, impedance, cooling, dielectrics, and short circuit. If any of these simulations fail, a designer must go back to the design and make corrections. If a designer has to make corrections, the design has to be re-optimized around those changes. The re-optimized design needs to be completely re-simulated again because the design is now different and all of variables of the design affect each other. My mock design required a lot of back and forth between designing and simulation.

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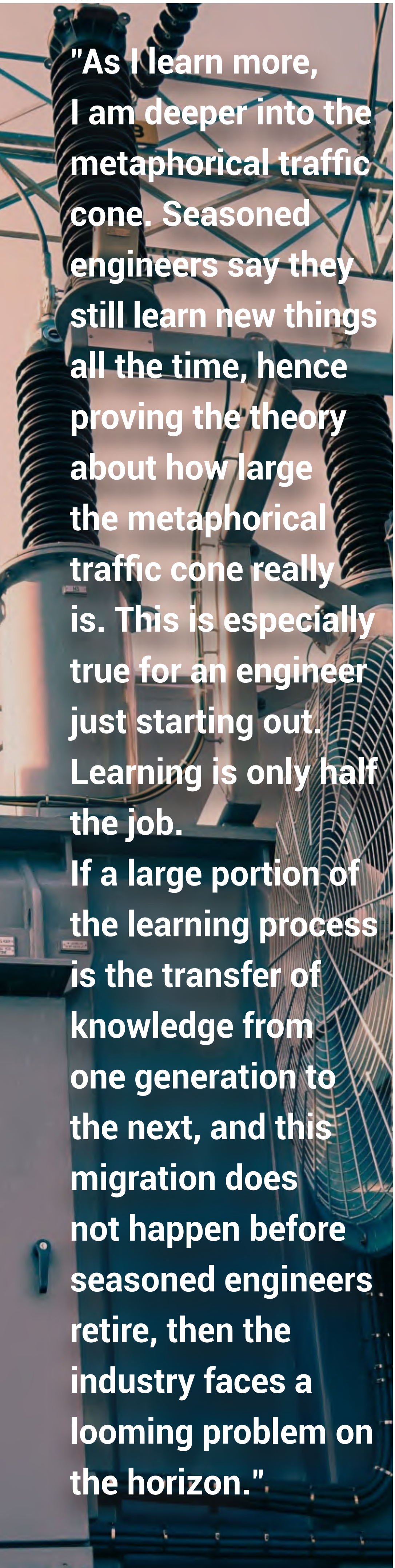

"As I learn more, I am deeper into the metaphorical traffic cone. Seasoned engineers say they still learn new things all the time, hence proving the theory about how large the metaphorical traffic cone really is. This is especially true for an engineer just starting out. Learning is only half the job.
If a large portion of the learning process is the transfer of knowledge from one generation to the next, and this migration does not happen before seasoned engineers retire, then the industry faces a looming problem on the horizon."

Eventually I did it. After what seemed like forever, I came up with a decent design that passed all simulations. I was proud. Next, I decided to compare what I came up with to the design that we actually manufactured. I figured since I worked so hard, the designs would be similar, and they were. While I definitely missed some opportunities for improvement that I did not quite grasp at the time, I had come up with a design that was entirely buildable, would likely pass on the test floor, and would transform voltage as necessary in the field. I considered my mock design – and the entire experience – to be a success.

Now for the message I want to relay, something important that got me to the point of a successful mock design. I have written about the general process and my experience going through that process, but I left something out – the teamwork along the way. Yes, self-study – reading guides and textbooks – was helpful, but having seasoned design engineers around to help was critical to my success. To have engineers around for guidance, ones that remember being in my shoes, but have become masters at their craft, was truly a blessing throughout the whole mock design process.

Fast forward to present time, where I am approaching the "dozen design mark", a team of engineers continues to be available to offer assistance. Thankfully, we have enough experienced people so I can spread my questions out as to not burden one individual too heavily. After I compliment them for being so helpful, they always give me the same response, "The only reason I know what to do is because I've learned what not to do." As humble as they may be, they really know what they are talking about, and I am grateful for the time they take to teach me.

I mentioned the design process is highly iterative, and, because of that, one can use various checkpoints along the way to learn something from an experienced engineer, which helps mold a young engineer into an experienced engineer. Experience is what makes an engineer more efficient, makes optimizing transformer designs faster, and helps to prevent too many simulation iterations. An experienced engineer can predict what might happen during a modeled simulation before they even run it. Becoming an experienced engineer is something to which I aspire.

As each day passes, I find myself learning more and more. As I learn more, I am deeper into the metaphorical traffic cone. Seasoned engineers say they still learn new things all the time, hence proving the theory about how large the metaphorical traffic cone really is. This is especially true for an engineer just starting out. Learning is only half the job. If a large portion of the learning process is the transfer of knowledge from one generation to the next, and this migration does not happen before seasoned engineers retire, then the industry faces a looming problem on the horizon.

I have been to a few conferences, read articles, and listened to podcasts associated with the power industry in the United States. Frequently a discussion about the aging work force comes up. From my observations, I can see why these discussions are taking place. If you are reading this, you are likely in the power industry, and can probably think of a few people you know with 35 to 45 years of experience that have recently retired. Some of you might witness these retirements often. As these fine individuals join the wonderful "life after work", they take their tribal knowledge with them. As these individuals retire, the average years of experience in the industry decreases. In an industry where knowledge, experience, and know-how are so important, we would be foolish to think that this will not have an impact.

I believe that, as an industry, we have the duty to mitigate the impact of this inevitable "brain drain" right now. Retirees moving to Florida with all of their knowledge is too great of a loss and a true detriment to allow. Of course, we can always hire them back as consultants, but that is not a good solution.

They want to stay retired and young engineers want them to stay retired. Written guides, like those from the IEEE, are great resources that continue to grow each year in an effort to help solve this problem. IEEE also helps in developing the culture of sharing information. This kind of culture is vital for continued advancements, growth, and maintenance of a reliable power network. A culture that converts tribal knowledge into written knowledge helps solidify that knowledge, and ensures that knowledge will not be lost. Companies must emulate this culture of documenting information and create their own internal written engineering documents. When future engineers have access to "lessons learned" from engineers who have "been there, done that", they can use that information to build their foundation as I did in my early training and continue to do. I cannot stress enough how important written documentation is! I have learned from seasoned engineers through written documentation and in person alike. I believe both are essential parts of teaching young engineers. The passing down of knowledge is something that can never stop and will forever be locked in an eternal pursuit. The torch of knowledge must be passed to the next generations. Those who receive this knowledge must recognize their own responsibility to carry it forward and pass it down, thereby completing the cycle so it can start over again.

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