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The Future of Substation Engineering – 3D BIM Design

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SUMMARY

Technological and computing improvements allow for owners, engineers, and construction contractors to take advantage of 3D designs and digital twins to improve the project lifecycle. A 3D design approach incorporates various sets of metadata and documentation to provide a single collaborative model for all design disciplines and stakeholders. The documentation generated from these 3D digital twins allows for teams to better collaborate, improve accuracy, and improve safety. This approach provides benefits such as reduced on-site delays, improved brownfield information, and improved safety design and on-site awareness.

KEYWORDS

3D BIM Engineering, Digital Twin, Intelligent Design, Future of Engineering, Safety Visualization, Reverse Engineering, Collaborative Approach, Transmission and Distribution Substations, Engineering and Construction

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With the growing complexity of transmission and distribution projects, new tools and technologies are essential to improving management of information, cross discipline communication, and stakeholder engagement. The improvements in technology and computing now allow for owners and their partners to manage the increasingly complex designs through an intuitive approach which provides benefits throughout a project's lifecycle. This new approach is developed utilizing 3D Building Information Management (BIM) technologies to develop an intelligent 3D model, also known as a Digital Twin. The Digital Twin provides a robust design which transitions through the life of a project from a design tool to a construction management and information repository, and finally into a maintenance and operational asset.

An intelligent 3D BIM model uses three-dimensional geometry to build a digital representation of an asset. These digital assets are linked with general and owner-specific metadata and then incorporated into an overall model which very accurately represents the intended design. Based on the initial data inputs, the overall model is able to populate various documents such as drawings, bill of materials, cost estimates, and maintenance & operations data without manual and error-prone human intervention. The outcome of such a digital twin is that stakeholders can make critical decisions earlier within a project's lifecycle, therefore reducing potential rework during the design stage and more impactfully during construction.

Current State of the Industry and Evolution into Digital Twin

The transmission and distribution industry is in various stages in the evaluation and adoption of new 3D BIM implementations and finally a digital twin approach. The initial stage, which is where all industry members are starting with is traditional two-dimensional (2D) non-intelligent computer-aided design. This approach has been in use for decades and is the foundation for all transmission and distribution substation documentation. 2D drawings and documents are required for all document control processes and are provided to engineering consultants, construction contractors, testing & commissioning contractors, and operations and maintenance personnel for use in daily projects. Utilizing a 2D non-intelligent approach requires additional steps within the engineering process which introduces the possibility of human error within a design. These errors could arise from information of a layout or schematic being updated on some drawings but not others, incorrect information gathering on Bill of Materials or cable schedule, or elements of a design being missed or incorrectly represented. In order to ensure a high-quality engineering deliverable, design reviews which account for these inconsistencies must be incorporated into the engineering process. These reviews require a large time commitment to ensure the details within proposed solutions are correct.

As teams begin to investigate more optimal solutions compared to 2D drawings, the typical avenues which are explored are intelligent 2D design and non-intelligent 3D modelling. These approaches provide separate benefits over traditional approaches, although they each carry over many of the shortcomings as well. Intelligent 2D approaches are able to provide easy access to standardized information and design checking but lack the consolidated improvements that a truly 3D BIM approach offers. Alternatively, non-intelligent 3D BIM grants the simplified and consolidated access to information but still relies on tedious and repetitive work to evaluate designs.

When the first stages of a true 3D BIM approach is implemented, there is a large variety of tools and packages which support the engineering process. These tools are typically heavily focused towards commercial and process & industrial applications and can not always meet the requirements which are important to the transmission and distribution industry. With increased adoption of 3D BIM solutions and design, the development of substation focused solutions is growing and also being considered. Once a 3D BIM approach is implemented and standard procedures are updated accordingly, projects are able to realize many of the benefits that a basic digital twin approach offers, although a full digital approach provides many improvements related to evaluation of designs, data processing, and analysis.

Finally, with a 3D BIM approach established, a digital twin can be further developed with the integration of various systems. This integration improves on the engineering and collaborative aspects of a 3D BIM approach and provides access and information to planning, purchasing, operations, and maintenance teams. A digital twin, as a single, easy-to-understand, source of truth, is applicable to all aspects of a project lifecycle and opens opportunities for consolidated information for analysis of systems which traditionally requires a large investment of resources to gather and organize.

Benefits of a Digital Twin

A highly accurate digital twin that is available from the early stages of a project provides an unparalleled capability to analyse and develop a project which has improved constructability, maintainability, and most importantly safety. As multi-discipline teams work together to develop a design, they all work within a single digital environment which allows for design clashes and possible construction constraints to be avoided without time-consuming documentation rework. Additionally, various possible designs can quickly be iterated upon to achieve a cost-effective infrastructure solution. The intelligence within the digital twin keeps track of all important information allowing for comparisons of dozens of potential solutions to be evaluated in a timeframe which is not achievable with traditional approaches.

With a large portion of project costs being attributed to the construction phase, it is imperative that contractors receive accurate documentation of the final product. A digital twin approach allows for time-consuming on-site rework to be more likely found during the design stage therefore reducing costly change-orders and potential schedule delays. Once the construction phase commences, the digital twin is transferred for on-site use to allow access to all relevant project information and the capability to immediately iterate any site changes within a master model which is then communicated to all stakeholders. The construction benefits when utilizing a digital twin model throughout the project lifecycle has been studied and found to be able to provide project benefits such as a 40% elimination of unbudgeted changes, up to 7% reduction in project time, and very importantly a savings of up to 10% of the contract value through clash detections [1]. These improvements not only allow for owners to have improved confidence in the designs which are issued, but to also have an opportunity to uniquely visualize the final product and provide comments and guidance based on company preferences. The images in Figure 1 illustrate the accuracy which is achievable when a digital twin is used from the early stages of a project and throughout construction where minimal differences are found.

Figure 1. Comparison of Design Digital Twin Model and Actual Construction
(Model : Left, Constructed Station : Right)

As a project progresses, the cost of modifications to a design increase. This increase in cost produces an inverse reaction to an organization’s ability to influence the cost of the overall project. If a change is required within a conceptual design phase, the high level change would only impact the engineering cost, irrespective of the change in complexity or constructability of the solution. As the project progresses into a more detailed design and further into procurement, the cost to make modifications introduces additional engineering and potential manufacturing costs that are more difficult to plan for and mitigate. Once the project is in the construction phase, any design modifications which need to be addressed have the greatest impact to the project cost and schedule, and are not preffered. This relationship between the progress of a project and the ability to influence costs is outlined on Figure 2. A digital twin model which involves intelligent design checking, construction and maintenance simulations, and cost analysis is able to keep a large portion of the changes in a project within the early stages where the ability to influence costs are much greater. As portions of a digital twin are used within planning and scheduling, further improvements to on-site execution are possible through the optimization of material and resources on a site. In complex projects, the digital twin used during the engineering and planning stage has been able to consolidate on-site work activites in order to eliminate complete outage periods for transmission lines, allowing for improved system reliablility and reduced project costs for utility customers. Through the adoption of a standard project execution process which incorporates a digital twin model, utilties and consultants are able to produce more accurate cost estimates and better control of the project costs through simulations and analysis of project construction execution and maintenance activities. The use of a BIM or digital twin model during the early stages of a project, increases the initial cost but also allows for a much greater amount of flexibility within the early stages of the design to influence the project costs. The ability to recognize risks and mitigate them within the early stages of a project would lower costs involved within later stages of the project when the ability and cost to make modifications to a design are greatly increased.

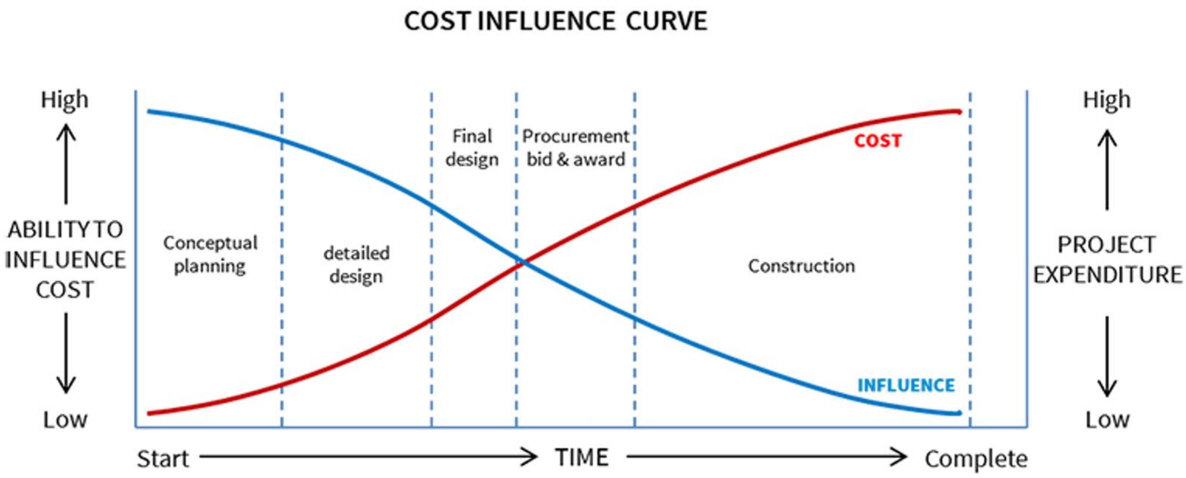

Figure 2. Project Influence Versus Costs Graph

Transmission and distribution owners are involved in numerous brownfield projects. In many cases it is common for these projects to not have complete information available during the design stage, leading to on-site findings which may introduce construction challenges or safety hazards. The digital aspect of 3D designs allows them to be integrated with many different tools and technologies to build a more comprehensive enviroment. Through the use of Light Detection and Ranging (LiDAR) scanners, brownfield projects can be digitalized and iterated upon. LiDAR scanners provide a point cloud of millions to billions of points in 3D space which represent actual location and visual conditions. These points provide a realistic view of the real "As-Is" condition of a site when compared to "As-Built" documentation which may have missed updates or incomplete information. When these point clouds are merged with a developing digital twin model, all stakeholders are able to view and analyze the project challenges and find potential hazards that could be mitigated prior to construction start or within schedule planning. The integration of the digital twin and point cloud allows for a type of "reverse engineering" when working on projects with limited documentation. The images in Figure 3 below provide examples of how new designs, shown in bright colors, can be built within existing designs while avoiding existing interferances.

Figure 3. Design within Actual Substation Environments

With safety being a priority for the transmission and distribution industry, it is important to build a safety culture not only on-site but throughout all organizations which are involved in these critical projects. Metadata which is built into digital twins can be used to visualize safety hazards and provide teams with immediate feedback on potential risks related to topics such as minimum approach distances. These safety related impacts reinforce the commitment that all stakeholders have towards zero-harm. The digital twin model that provides engineers and designers with important safety information is then transferred to on-site teams which allows for safety analysis and visualization to be included in daily toolbox talks. The visual aspect of the safety analysis allows for all involved teams to have an improved understanding of the hazards and mitigations that are at a particular project site. The digital twin can provide a highly interactive environment for various feedback and suggestions to be evaluated and implemented. Figure 4 below illustrates how a digital twin of an existing site is used to visualize an energized bus bar relative to a crane which will be operating nearby for a transformer bushing replacement. Clearance distances can be analyzed based on various equipment locations to determine an effective and safe approach to the work being performed.

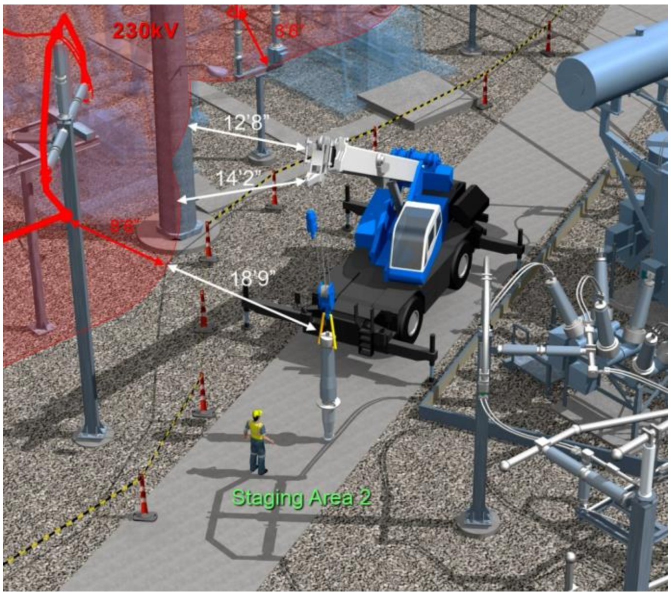

Figure 4. Safety Analysis and Visualization

Challenges of Implementing Digital Twins

Developing a standard process which incorporates a digital twin model requires investment of time and resources and careful planning. Large factors that are included within this development of a digital twin approach are the conversion of existing standards, conversion of existing traditionally developed projects, and training of internal and contractor resources. When planned out and well executed, these factors help in delivering a smooth transition from a traditional 2D approach to a 3D BIM and digital twin process.

In order to maintain business continuity, a conversion of existing standards which do not greatly deviate from the traditional approach is extremely important. Resources within all aspects of a project lifecycle have a developed understanding of how information is presented and utilized. In order to transition to the initial stages of utilizing a 3D BIM and alter a digital twin model, it is important that the organization of information is kept similar. Although information would be presented in a similar way, the process in which that information is generated would be improved by introducing automation and design checking. This approach also allows for existing business processes such as document control and interaction with contractors to be mostly maintained while introducing the 3D/digital twin model as an additional value-added document. This approach, especially in the early stages of 3D BIM adoption, allows for a smooth transition between processes without interruptions in project adjacent processes. Additionally, through minimal modifications within standards, it is possible to temporarily maintain both existing and 3D BIM approaches for project execution as engineers, drafters, and stakeholders are made familiar with the changes to the execution of projects.

Although greenfield projects can efficiently be developed within new digital twin processes, the majority of executed projects are on existing assets which would require time consuming and cost prohibitive work in order to fully convert all existing documentation to a digital twin. An approach that many are using during the transition to a 3D BIM and digital twin process is to incrementally update brownfield documentation to the new toolset and process. By keeping unmodified information within the documentation as-is and including existing electrical layouts and sections as overlays on the digital twin, a project is able to efficiently progress with a green-lined removal revision and an installation revision which is fully generated from the mixed digital twin and 2D documentation. Through this process, existing documentation would slowly transition to a digital twin approach without requiring time consuming, and likely error-prone rework of As-Built documentation into a digital twin. This also allows for many aspects of the digital twin approach to be realized while maintaining minimal traditional 2D drawbacks.

Another critical aspect in maintaining efficient project execution is the proper training of both internal and external resources. In order to properly develop a digital twin model, it is important that equipment is not only accurately modelled, but that the data that is associated with it is also well organized and consistent throughout projects. To ensure that everyone within the project execution is familiar with the process, from standard equipment model development to the integration of materials, a detailed guideline should be developed prior to beginning projects with a 3D BIM/digital twin focus. These guidelines should then be evaluated through pilot projects in which feedback is provided and the guideline develops as input is provided from engineers, drafters, and project stakeholders. Through effective training of personnel, a consistent implementation will provide the benefits of a digital twin approach without requiring manual rework and modification.

The Future of Digital Twin

As additional information is introduced into a 3D design, more possibilities are opened to assist project teams in performing the daily important infrastructure work. With implementations of schedules and budgets, 3D designs are able to be transformed into 4D (3D model + time) and 5D (3D model + time + budget) models which assist with scheduling, budgeting and risk mitigation. An example of a 4D model is shown in Figure 5. In this representation, the schedule can be visualized on the 3D model depending on the color of different substation elements. As the schedule is updated with actual values, the color of the equipment and materials will be automatically adjusted to represent the impact to the project. This immediate and comprehensible feedback allows for improved schedule awareness and provides an immediate understanding of where the project is, as green represents on-time activities and red addresses late tasks. Furthermore, if budgets are included within the project scheduling tool, these costs can immediately be updated based on the progress of the project and provide an accurate forecast of actual costs due to various schedule conditions. When used by project management teams, these additional project deliverables provide project progress and budget adherence understanding to all stakeholders. These implementations are currently in place in numerous large-scale projects to realize the design, safety, and cost benefits of the new technologies which are available to the transmission and distribution industry.

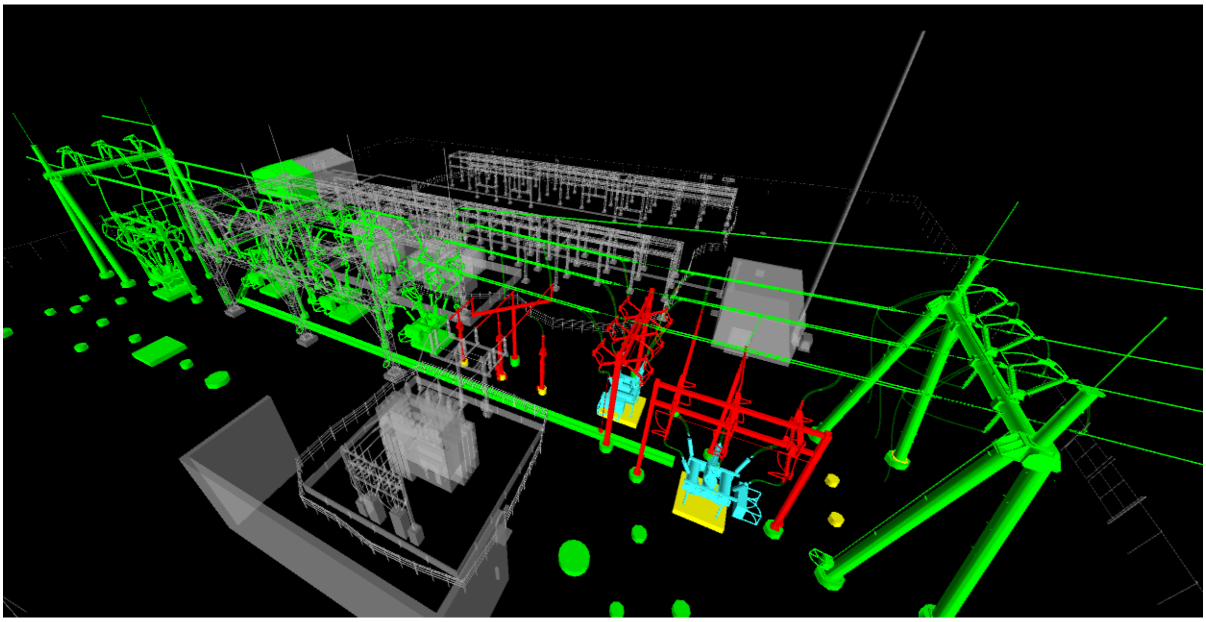

Figure 5. 4D Scheduling of Brownfield AIS Substation

Integration with corporate systems and other data is an important aspect in the analysis of systems and projects. Although data can be inputted within a digital twin without integration with external systems, this introduces the possibility of errors when data is not updated in a timely manner or is entered incorrectly. As digital twins become more prevalent, third-party integrations will likely be produced to link together various systems and support the production of project documentation. Integration with systems such as scheduling, procurement, standards, and operation & maintenance would provide additional up to date access to latest important information that could impact projects.

By integrating scheduling and procurement systems with a digital twin, it would be possible to automatically update scheduling details based on latest procurement lead times, and better conceptualize project execution timeframes. This linkage would also allow for 4D schedules to dynamically be updated based on schedule inputs and provide accurate metrics based on previous performance and latest information.

With equipment accurately stored within numerous project digital twins, an overall database of equipment usage and location can be extracted and analyzed. This information would then be feasibly integrated with operations and maintenance tools to provide reminders and schedule maintenance activities to better ensure that equipment is properly taken care of throughout the duration of its expected lifespan. This database of engineering information would also allow for tracking of equipment, and analysis of events which may impact multiple sites depending on equipment that is installed without the manual process of collecting data from document control systems.

An extremely beneficial integration of a digital twin would be with SCADA data reporting. All aspects of a substation could be integrated and stored related to equipment operation, system electrical operating conditions, and ambient conditions such as temperature and wind speed. By consolidating the vast amount of generated data from the system, big data analysis would be possible to better understand the impact of certain engineering choices on the system without requiring additional studies to be performed. Scenarios such as better understanding failures of equipment and predicting failures of other equipment would assist in outage planning and ensuring that the transmission and distribution assets remain reliable for the safe delivery of electrical power.

The transition from traditional 2D design approaches to a 3D intelligent “digital twin” project lifecycle is quickly being developed for many utilities around the world. These digital twin project models are becoming more important to not only engineers, but also construction contractors and owners for the management of schedules, maintenance, and operation activities at critical sites. With developments to high-speed internet access in remote areas, augmented reality (AR) technologies, and business integrations, the digital twin process has many different avenues into which it could be expanded to while continuously targeting its goals of reduced costs, zero-harm, and improved collaboration.

As the grid of the future develops, engineering tools and techniques such as 3D BIM and Digital Twins will need to mature to support the growing complexity of systems. By adopting these technologies and incorporating them into the project execution lifecycle, owners and engineers can begin to better understand the capabilities which are available to them. This understanding allows for improved project execution efficiency, project planning, and budget and schedule tracking. This initial adoption of BIM technologies will allow for digital twins to begin forming by integrating system data and performing analysis of system conditions on intelligent data models. The addition of system data and complex data analysis will open new opportunities for the transmission and distribution industry to make more informed decisions related to system planning and modifying and integrating systems to the grid.

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