Framework and data management for digital nuclear power design system

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Abstract: In order to implement plant lifecycle management and digital handover at design stage, and more importantly to equip with more advanced and efficient design means, nuclear power design institute, like SNERDI, is transforming from current document-based design mode to more advanced digital design mode, which features collaborative design on a single and unified data source. A digital design framework consisting of “three platforms and one center” is structured. The three platforms are the 3D plant layout platform, the system design collaborative platform, the simulation and analysis platform, and the center is the data management center. The function features of the three design platforms are described, and the data center is explored in more detail. The plant information model comprising of design objects, design data (model, document, and attribute), and the relationship among them is proposed as the underlying database structure. And then the data load and quality assurance mechanism is introduced. Finally, the application matrix of the data center for engineering usage is presented. Overall, the framework and the data management found the theory basis for the establishment of a complete digital design system.

Key words: digital design; data center; data management; quality assurance; digital handover; 3D model; nuclear power design

1 introduction

“Industry 4.0” lays emphasis on the product lifecycle management (PLM)[1,2] based on a single and unified data source, which depends on and urges the digital handover[3] (different from current document-based handover) of design results to construction and operation part. In order to implement plant PLM and digital handover at design stage, and more importantly to equip with more advanced and efficient design means, nuclear power design institute, like SNERDI, is transforming from current document-based design mode to more advanced digital design mode.

The content of digital design system differs industry by industry. The aviation and vehicle industries have adopted 3D product design environment for decades, which also supports pre-assembly, parallel engineering, and virtual simulation as well[4]. In chemical and energy industry, the plant layout is performed in a 3D collaborative environment, in which buildings, equipments, piping components, etc., are modeled and presented together[5,6].

Though the 3D-model-based product design or plant layout is much mature and widely adopted, it covers less on design areas like physics, thermal hydraulics, process design, instrument and control (I&C), mechanical analysis, etc. In addition, the 3D environment is seldom used as a data management platform to store all design data of various formats and sources. Thus in order to develop a full-disciplined collaborative design environment with a single and unified data source, the framework and data management of the digital design system are studied and presented.

2 design platforms of digital design system

Nuclear power design involves many disciplines or majors (including site, fuel, core, radiation protection, equipment, process systems, electrical systems, instrument and control, building and structure, layout, mechanical analysis, safety analysis, etc.), produces various forms of design output (including text file, drawing, 3D model, etc.), uses near hundred software with or without collaborative requirement, and goes through different quality assurance (QA) procedures, therefore the digital design system shall comprise several platforms (instead of the only 3D environment) according to disciplines, software, output forms, and collaboration requirements.

The digital design system, if developed, shall provide a collaborative design environment with efficient data transferring mechanism based on the single data source and unified data model (especially for system design and plant layout), shall provide integrated design process environment in which software, input/output/delivering data, and even knowledge is incorporated into each design activity (especially for traditionally non-collaborative areas such as physics, thermal hydraulics, stress analysis, safety analysis, etc.), shall provide data-based project management means for project planning, change impact analysis, interface margin analysis, configuration and baseline management, digital handover, and data-based quality assurance as well.

In short, the digital design system establishes a multi-disciplined and data-centered design environment, and in considering the capability of current 3D and 2D design software, it shall comprise "three platforms and one center" as its framework. The three platforms are "3D plant layout platform", "system design collaboration platform", "simulation and analysis platform", and the center is "design data management center" (short as data center) as illustrated in fig. 1.

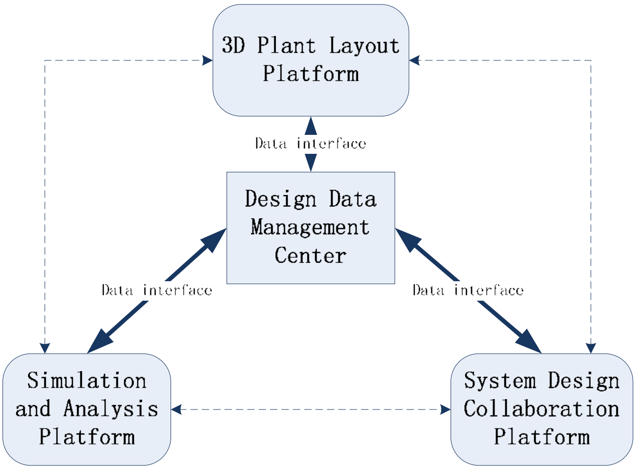

Fig. 1 the digital design system comprising three design platforms and one data center

The 3D plant layout platform[7,8] is a 3D modeling collaborative environment in which designers perform plant layout for buildings, pipelines, instruments, equipments, steal structures, support components, penetrations, and even cables. In addition to 3D plant modeling and navigation, the platform is also used to produce drawings, bill of material (BOM), collision check results, and process simulation. The platform shall load in other models like steel structure models (by Xsteel), support and hanger models (by Support Modeler), and building information models (by Revit), thus form a complete 3D digital plant. Currently several commercial software are applicable such as PDS, PDMS, and SmartPlant 3D, etc., and the application of the 3D platform is much mature and widespread.

The system design platform[9] is a "2D" collaborative working environment in which designers perform piping & instrument diagram (P&ID) and components design for process system, DC/AC distribution, wiring, and components design for electrical system, structure, control logic, and signal design for I&C system, etc.. In order to implement the digital design mode, The platform shall build-in or customize standard data model for all types of system components, including stencils, symbols, connections, attributes, etc., and the component information (including identifications, relations, attributes) shall be stored in a unified database rather than in documents or drawings. Besides, the platform shall incorporate quality assurance process, which includes release management for documents and drawings, version management for items and data, and authority management for operations as well.

Beside plant layout and system design, nuclear power design also involves simulation and analysis works such as reactor physics, thermal hydraulics, radiation protection, accident analysis, stress analysis, etc. they are currently performed in separate servers or personal computers by commercial software (like CFX of fluid dynamics) or specified ones (like reactor physics), using text or finite element model as input, producing reports or drawings as output. From any perspective, these simulation/analysis works cannot be all done in single software as the 3D layout or the 2D system design platform does. Hence the simulation and analysis platform[10] shall be a "virtual" platform, in which users can define control-flow and data-flow for design process, plug in various software or office tools, customize input/output data template. Engineers perform simulation/analysis work in this unified virtual platform by invoking pertinent process, software, and templates, and store or transfer design data in the same platform.

Overall, the 3D layout platform realizes the digital design mode (i.e., collaborative design with unified data source) by 3D modeling; the system design platform realizes by object-oriented predefined data model; the simulation and analysis platform realizes by process-oriented integrated software and template. Though each platform provides collaborative working environment within their own, it is rather difficult to set up collaboration mechanism among the three platforms, not to mention that the platforms may have not been developed or functioned ideally. Though each platform contains underlying database where design results are stored, it is rather difficult to transfer or store data among the database due to different data structure and inaccessibility. Therefore if only the three design platforms were developed, the iteration efficiency (say, between piping and stress analysis), the automation of data transferring, the design results consistency, the design change impact analysis, and others would achieve no essential advancement compared with traditional "single disciplined & document based" design mode. This gives competent reason to build a unified data source, though not all.

3 design data management

Although in the "tree platforms and one center" framework, the data center is mainly used to communicate and store the design data for each platform (thus form a single data source), the data center itself is a relatively independent system which organizes, stores, treats, relates, visualizes all forms of design data and provide application service for engineering usage, even if the "document based" design mode still prevails.

3.1 plant information model from design perspective

The design information for a nuclear power project can be categorized into design result, intermediate archive, workflow, external feedback, base library, and knowledge. Among all, the design result is the most important and complicated which comprises of design object, design data, and design relationship in view of information organization. Design objects refers to both real plant items in systems, structures, and components (SSC), and virtual objects in reactor physics, radiation protection, accident analysis, mechanical analysis, and other simulation activities. (hence design objects = items + activities). Design data refers to 3D models (CAD/CAE/CAPP models), documents (doc/xls/txt suffixed files & pid/dwg/dgn/vsd suffixed drawings), and object attributes (in form of single parameter and multiple parameter like table). Design relationship refers to the dependency, membership, inclusion, input/output and other relations among objects, documents, attributes, and design activities. Overall, object, data, and relationship constitutes the kernel of plant information model[11-13], whichever indispensable, as shown in Fig.2.

Among the three types of data, 3D models and documents exist independently in form of electronic file, and are usually stored in organized directories. But objects' attributes (say, a pipe's design pressure) must attach to the object, otherwise are ambiguous or even meaningless. Hence attributes shall be organized by "object-orient" method, that is, each object is defined with a set of attributes and users pinpoint the attribute via object-attribute approach. In practice, to avoid repeatedly defining the attribute set for each single object (image one pipe or one cable is an object), the design objects are usually classified into classes, and objects of a class own the same set of attributes. The granularity of a class should be tuned carefully. Differed with the big classes (pipe, valve, instrument, pump, etc.) adopted in commercial software (say SPF of Intergraph or Maximo of IBM), the data center shall provide more specified classes for users to choose because after all the attributes of a control valve are quite different from that of a safety valve during design stage. Besides, if one equipment has independent components (like a pressurizer has several heaters), then their attribute boundary should be clearly outlined to avoid common attributes shared by both. Overall, the classification of the design objects and the definition of each class's attributes are much sophisticated and tedious, but lay the foundation for data management.

Each attribute consists of value and other information that describes it, which is usually termed as data header or meta-data. A data header (similar as file header) includes name, form, unit, field, version, code, QA record, date, source, baseline, domain, rule, handover, explanation etc., and are used for identification, storage, quality assurance, or application of the data. Form refers to number, character string, or enumeration if it is a single parameter, and vector, table, or curve if it's a multiple parameter. For a single parameter, the unit should be assigned, and for a multiple parameter, the fields (or columns) should be defined. Each data can be assigned version, source, date, and QA record when the value is loaded into the database just as a file is archived. Domain is to distinguish attributes with the same name but have different values, or to tell a data whether it is a design result or a feedback one. Handover means whether this data is within the scope of digital handover. In addition to the above meta-data, more header information can be defined such as alias, importance, independency, etc, according to data management requirements. By the way, since multi-parameter data is to be stored as a whole, it is more suitable to use non-relational database[14], such as Mongodb, where data is stored in "key-value" approach.

The relationship among objects, documents, attributes, and workflows is also important and is easy to be neglected in conventional design mode and document-based handover mode. An object relates another one if the former logically/spatially includes the latter (system-equipment), or comprises of the latter (equipment-component), or connects the latter (component-cable), etc. The inclusion relation is usually used to organize the objects, say in form of plant breakdown structure (PBS) or geographic breakdown structure (GBS). An object (or an attribute) relates a document provided that it is contained in the document; no matter the document is a text file like report or a drawing like system diagram. So each object (or attribute) owns a list of pertinent documents (surely can be sorted by closeness). The object-document relation (or attribute-document relation) can be set up by "full text search[15]" technology, and lays the foundation for "change impact analysis[16]". An attribute relates another one if there is a functional or statistical relationship between them, and is usually used to generate data value or check data correctness. The data center shall provide certain modules in which users can define elementary functional or statistical rules. The data-workflow relationship is a bridge between the data center and design activities. Users define a working activity, and select sets of the data (models, documents, attributes) as the output, input, or delivering ones respectively. Then engineers can retrieve input data, load in output data, and transfer intermediate data to other engineers with high level of automation in name of that activity. And project manager can get important information, such as interface margin, upstream-downstream consistency, and others from the data-centered workflows.

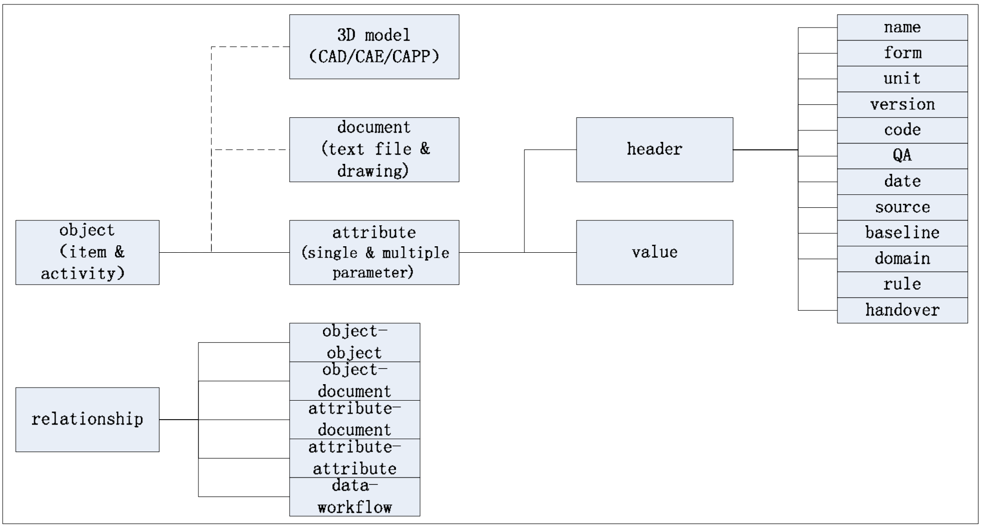

Fig. 2 the nuclear power plant information model from design perspective

3.2 data load and quality assurance

The above plant information model is used to design the underlying database structure, and provide approaches for information presentation and application. However, different from other industries, the design results are currently stored in various design platforms and documents, unordered. It is really a tough task to load in the data from platforms and documents, not to mention going through the quality assurance[17,18] (QA) procedures.

The data load shall follow certain procedures in order to satisfy the quality assurance requirements, as is illustrated in Fig.3:

1) The developers establishes the interface between the data center and each platform, which contains the one-to-one correspondence table and format transition rules for each data, and also designates the format for documents that publishes data, so that data in the document can be accurately read by the data center. Besides, graphical user interface (GUI) is also needed since some data value may be typed into the data center instead of via platform or document.
2) After having finished a design work, the responsible engineer draws a data template in the data center. In the template, sets of data are selected and arranged according to the data-workflow relationship, and also the data source (platform, document, or GUI) for the template is designated.
3) The data center then starts to read data value from the source and fill the template according to the correspondence and transformation rules (except for GUI). After signed, the filled template then is passed down for check and review procedure.
4) After having gone through the QA procedure, the data center reads the data value from the filled template and retrieve the QA record from the procedure, and then inserts both into the database. The “write” operation would only insert new version data, and would never override old version ones.

As can be seen from the above procedures, the data load process is actually part of the project design process since it is initiated and operated by responsible engineers and also QA procedure is integrated just as that for document release. So it is natural to merge the data center with original document management system, forming a comprehensive data management system (DMS) for nuclear power design.

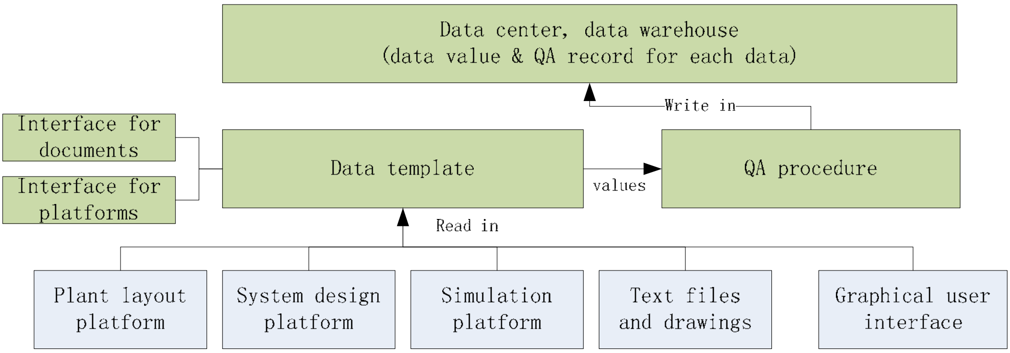

Fig. 3 the data load and quality assurance mechanism for data center

3.3 Application of data center

Once the data have been loaded (or partly loaded) into the database, applications of the data can be implemented to facilitate project design and project management, as well as digital handover. The applications can be divided into four areas, that is, view & search, design aid, PM aid, and external usage, as illustrated in Fig. 4.

External usage	Digital handover	Regulatory assistance	Feedback data load	Vendor linkage	Mobile application
PM aid	Change impact analysis	Margin analysis	Baseline management	Consistence check	Project statistics
Design aid	Input file automation	Output file automation	Data auto transfer	Sharing & collaboration	Knowledge management
View & search	Object & attribute view	Document view	3D model view	Data search	Relation search

Fig. 4 the four areas of data center application

Design objects are organized and presented in PBS or GBS tree, and when an object node is clicked on the data center, all its attributes would show, including data value, meta-data information, QA record, and all historical versions. Since multi-parameter attributes are allowed, the data value of a vector, a table, or a curve shall be presented in its proper format (this differs a lot with commercial data management softwares where an attribute is simply a number or a character string).

Documents and 3D models are presented in separate pages, respectively. Usually, documents of a project are organized by volume set, or users can find a document by key word search. Upon click, the document would be opened and its content would be shown on the screen. Plant layout 3D models are shown as a whole on the screen by 3D technology, and move, rotation, section, zoom handles are provided for user navigation. If an object is clicked in the PBS or GBS tree, its corresponding 3D part would be highlighted, which brings a bridge between the objects and the 3D models.

All the objects, attributes, and documents can be searched by key words including name, tag number, data value, QA record, or others. Besides, all the relations can be searched out. Starting from an object, users can find all the other objects that connect it and all the documents that contain it. Starting from an attribute, users can find all the documents that contain it, all the other attributes that depend on it, and all the design activities that produce or quote it. The relations can be established at the very begin by manual or at any instant by “full-text” search technology.

Engineers not only load in data value to the data center, but also use it as a design assistant. The data center can produce input files and output files for project design provided that proper file templates were pre-defined, and can transfer data to the down-stream activities provided that the data-flow is defined in the data-workflow relationship. An engineer group can also set up a data pool, in which data is shared and updated in real-time, so as to facilitates the design iteration and collaboration. What’s more, all the design material (i.e. input cards, intermediate files, related documents, and data) can be stored in the data center, which provides a useful tool for knowledge management[19].

Project managers use the data center as a powerful PM assistant. Since all the relations between objects, attributes, and documents are manually or automatically established, it is easy to draw the “change impact map” for an object or an attribute. Therefore the original important but difficult “change impact analysis” can be handled easily in the data center. Managers can also analyze the margins for each design activity by counting the difference of each data for being input value and output value. As for baseline management[20] (part of configuration management[21]), it is feasible to prescribe a certain version of data (or last version before a certain date) as a baseline, and demand all the activities to produce design results based on the baseline data. For data consistence check, it is possible to set up various data rules which can be automatically executed by the server, or compare all the data values in the documents by method of “full text search”. Finally, statistic information out of the data center can be generated to reflect various aspects of a project, such as progress, spent man-hour, mile stones, risks, and others.

Among all external usages, the digital handover is worth introducing. Digital handover is a new and advanced way to transfer design results to plant construction part or utility, compared with traditional document-based handover mode. Currently there are no standards or reference case to follow for nuclear power design, but generally the scope of handover shall cover plant layout 3D model, text documents and drawings, objects’ attributes, and important relations. The 3D models and documents/drawings can be simply delivered by file, but the objects’ attributes and relations meet difficulties. Were the data center developed and applied for project design, the digital handover can be easily done. First, the project manager determines which part of data needs to be transferred (only a small portion of design attributes is useful for construction or operation), then exports these data to a particular formatted file. The receive part then can restore all the transferred objects, 3D models, documents, attributes, and relations on the data center for plant operation and maintenance usage. Or another way is to export the data into a zip of word/excel files, and then deliver it to the receive part, whichever.

4 summary and prospect

The 3D plant layout platform, 2D system design platform, simulation and analysis platform, and the data management system, comprise a complete digital design framework for nuclear power design, realizing the multi-discipline and collaborative design mode with a single and unified data source. Besides the software development, the digital design system also depends on and promotes the reformation of the “production relation”, which includes the closeness of disciplines, the refinement of QA system, and the alteration of human resource. For design disciplines, process, electrical, I&C would share data and adjust progress, hence become more relevant. For quality assurance, it becomes natural to establish data-based QA system, and tools such as data consistence check, data version management would be equipped. For human resource, beside the IT team for development and maintenance of the platforms, each discipline shall train at least one implementation staff who shoulders the task of setting up the objects, activities, meta-data, data template, document automation means, etc., as well as management or maintenance for his own discipline.

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