Computer-aided 3D routing of Instrumentation Cables

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Abstract:
This paper presents the process of 3D routing of Instrumentation cables for a thermal power plant using the integration capabilities of Instrumentation, Electrical and 3D modules of Smart Plant suite. Efficient use of integration linkages amongst various modules of Smart Plant suite is explained. Workflow of preparing cable schedule for Instrumentation cables in an integrated environment is discussed. The processes of routing the Instrumentation cables in an existing 2D CAD software and in 3D software are compared and rules and constraints applied on cable tray network in 3D module for routing the Instrumentation cables are presented. The output of 3D software based routing of Instrumentation cables is compared with the output of 2D software based routing of Instrumentation cables and presented. Finally, the issues faced during the complete process and their resolutions with learning are discussed.

1. Introduction

Cables are necessary for establishing Electrical, Control and Instrumentation network among various electrical items. Cables are barely noticed by anyone but they are 'simply there' and everywhere. We all use the various electrical devices and appliances or internet to connect or communicate with outer world, without knowing the complexity of supporting cable network and underlying infrastructure. Root level detailing is required to establish a working cable network. Cables damaged during installation can cause service failures and trigger the disasters like fire break out, short circuits etc. The small details in setting up cable network can make the differences.

In a power plant, number of cables is huge and underlying cable network is very complex. The main function of cables in a power plant is to transmit Instrument Signals, Control Signals, and Electrical Power.

Routing of cables is a very critical aspect of power plant engineering and is a cumbersome task. This is not only due to the intrinsic complexity of the system, but also the number of

rules and constraints applied on the cable routing process. A wrong connection can lead to the failure of entire power plant.

Generally, routing of cables for a power plant is done in 2D software and based on the information, cable schedules are prepared for the cable installation at sites. PEM is the project engineering division of BHEL and routing of cables for major portion of power project is being done at PEM. It is always remembered during the engineering phase that careful routing of cables and preparation of cable schedule is very important to deal with cable network related issues and it can also save the significant amount of cables to avoid the potential cable shortage or cable wastage problems at site.

In the present time, increased use of technology can be seen universally in each and every field. In power plant, the usage of technology for the 3D modeling of power plant has become vital for many reasons like interference checking, space optimisation and many more. The 3D modeling of equipment, piping, civil structure, HVAC, cable trays and hangers & supports is already in practice, but

routing of cables in 3D software is yet to catch the speed. One of the major advantage of using 3D software is the output generated from the software. It is better understandable and more clear in visualisation. Currently, in PEM, the cable routing process is manual, partially supported by an in-house developed 2D software. Unlike 3D software, this software does not trace the actual cable route in 3-dimensions.

The methodology adopted in PEM for routing the Instrumentation cables in 3D environment is presented in this paper. Though cable routing is an entirely rules and constraints based process, still it is found that only a few automated 3D software are available in market to cater the requirement. At present some companies are providing the cable routing module in their plant design 3D modeling software. Some of these companies are Hexagon-Intergraph, Bentley, AVEVA.

BHEL-PEM has integrated plant design system, largely based on SmartPlant suite. The different integration interfaces exist amongst Instrumentation, Electrical and 3D modules of SmartPlant. These modules are data-centric, rule based, and customisable to an extent in their respective domains. Using these modules and existing interfaces, an approach was drawn for routing of Instrumentation cables. The cable data transfer interface exists between Instrumentation and Electrical modules and Electrical and 3D modules. To leverage the interface between Electrical module and 3D modules for cable data flow, Instrumentation cable data from Instrumentation module was transferred to Electrical module and further to 3D module where the routing of cables is done.

2. Existing method of routing the Instrumentation cables

Electrical department of PEM uses an in-house developed software for cable routing. It was developed by BHEL's corporate R&D[1] division in association with PEM. Initially it was developed on dbase[2] database for Microsoft DOS but later migrated to Microsoft Windows XP, 7 and later versions. This software is used for generating the cable schedules based on cable listings including routing information.

Cable trays network in the software is created by giving node-to-node information of cable tray

sections like section name, section length and cable tray type (Power or Signal). This information is extracted from cable trays layout drawings, prepared in 2D AutoCAD format. The extracted information such as cable tray section name, section length, near node, far node is stored in excel spreadsheets. The method of fetching this information is either manual or using macros of spreadsheet or AutoCAD. These spreadsheets are imported into the cable routing software for creating the cable trays network.

Cable lists are also fed in the software using excel spreadsheets. These spreadsheets are prepared manually but in a pre-defined format which has UNITCABLENO, FROM, TO, PURPOSE, REMARKS columns.

Rules and constraints like connection of each node, calculating the shortest path for cable are built-in the software and are applied on cable trays network. Rules like cable margin at both ends, cable margin at turn features can be defined on the fly when routing the cables for a project.

3. Integrated Plant Design System

The following major engineering modules of SmartPlant suite from Intergraph (now Hexagon) are available in PEM:

SmartPlant Instrumentation- SmartPlant Instrumentation is a schematics module of Intergraph for Instrumentation & Control System Engineering. It has the capability of generating instruments lists, datasheets, reports, hook-up diagrams, BOQ[3]s, cable schedules and cable interconnection diagrams among others.

SmartPlant Electrical- SmartPlant Electrical is the engineering module for handling Electrical power system data in a power plant. This module is for preparing electrical single line diagrams, control schematics, cable sizing, cable drum cutting schedule, cable schedules, electrical load lists, cable BOQs, etc.

SmartPlant3D- SmartPlant3D is a plant design 3D application. It is a data-centric, rule-and relationship based platform for modeling various entities of power plant like piping, structure, equipment, instruments, ducts, cableways, cables, hangers and supports etc.

Key components of the Smart 3D technology architecture are:

- Intelligent Rules and Relationship – It captures and maintain engineering tacit knowledge and

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[1] R&D- Research & Development

[2] dbase- One of the first database management systems for microcomputers, and the most successful in its days

[3] BOQ- Bill of quantity

expertise to drive 3D design with an extensive and customizable rules which enables objects to interact in an intelligent and automated manner.

- Concurrent design – Leverage the multi-disciplinary users to work on common, data-centric 3D platform simultaneously. Efficiency increases through real-time concurrent design. Efficiency increases through real-time concurrent design.
- Automation – Automatic generation of drawings and reports with minimal user inputs which removes the routine work, and enables a focus on value-added engineering.

SmartPlant Foundation- SmartPlant Foundation is a Plant Information Management module which acts as a data exchange hub between the above engineering modules of Intergraph.

4. Integration interfaces between different modules of SmartPlant which are used in Instrumentation cables routing

i. 2-way integration interface exists between Instrumentation and Electrical modules as well as between Electrical and 3D modules. No direct integration interface exists between Instrumentation and 3D modules.

ii. 2-way integration interface for cable data transfer exists between Instrumentation and Electrical modules via Import managers of individual modules. Import manager uses Microsoft-Excel spreadsheets for import/ export functionality.

iii. 2-way integration interface for cable data transfer exists between Electrical and 3D modules via Foundation module.

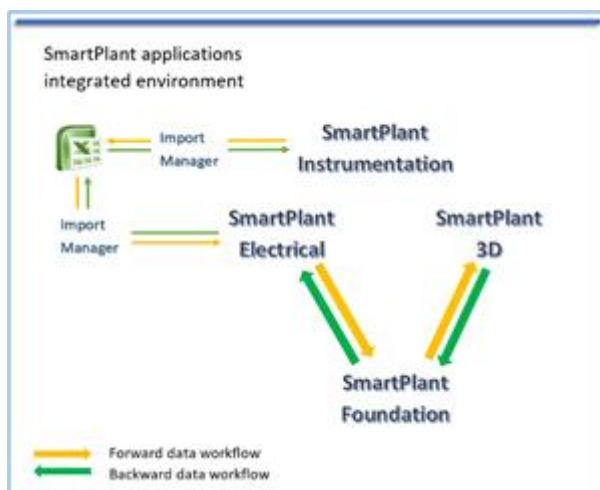Integration environment amongst SmartPlant applications is shown in Fig.1

Fig. 1:SmartPlant applications integrated environment

5. Methodology adopted for routing the Instrumentation cable

The adopted methodology comprised 3-steps viz. Data Creation, Data Transfer and 3D Modeling. In step-1, Instrumentation Signals cables were created in Instrumentation module with cable number, description, cable type and number of pairs in a cable. Termination of cables was also done between signal source ends and DCS panel ends.

In step-2, cable schedule was extracted from Instrumentation module and was imported into Electrical module where detailed cable specifications were prepared and applied to imported Instrumentation cables. Cable schedule was published from Electrical modules to 3D module with cable number, description, cable type, names of signal sources and names of DCS panels. Cables were created and auto-correlated with existing signal sources and DCS panels available in 3D module.

In step-3, the routing of cables was carried out in 3D module on the cable trays network. Rules and constraints were applied on cable trays network before starting the routing of cables.

The following sections aim to explain these steps in more detail.

Step-1: Data Creation- Instruments and Drives which are the major signal sources in a power plant were available in the Instrumentation module. These entities were created in the Instrumentation module during the instrumentation engineering phase of the project and deliverables such as Schedule of Instruments, List of Drives were extracted. In this step, signal sources, DCS panels were created for terminating the cables at source and destination ends. Instrumentation cables were created for all the signal sources with cable name/number, cable type, description, number of pairs in a cable. Cable schedule prepared in Instrumentation module as shown in Fig.2.

Cable_Name	Cable_Type	Cable_Description	Signal_Source	DCS_Panel	CABLE_PURPOSE
CRE01-HT-C001	Type-G (IOS)	8P X 0.5 MM² MULTIPAIR TWISTED G-TYPE	1HLB10AN001	1CVP01	Control & Monitoring
CRE01-HT-C002	Type-F (IOS)	2P X 0.5 MM² MULTIPAIR TWISTED F-TYPE	1HLB10AN001	1CVP01	Control & Monitoring
CRE01-HT-C003	Type-G (IOS)	8P X 0.5 MM² MULTIPAIR TWISTED G-TYPE	1HNC10AN001	1CVP01	Control & Monitoring
CRE01-HT-C004	Type-F (IOS)	2P X 0.5 MM² MULTIPAIR TWISTED F-TYPE	1HNC10AN001	1CVP01	Control & Monitoring
CRE03-HT-C005	Type-G (IOS)	8P X 0.5 MM² MULTIPAIR TWISTED G-TYPE	1HLB20AN001	1CVP01	Control & Monitoring
CRE03-HT-C006	Type-F (IOS)	2P X 0.5 MM² MULTIPAIR TWISTED F-TYPE	1HLB20AN001	1CVP01	Control & Monitoring

Cable schedule was extracted in excel spreadsheet for the next step which is Data Transfer to Electrical module.

Step-2: Data Transfer - In Electrical module, cable schedule was imported through Import Manager (a utility of Electrical module) from the excel spreadsheets which was extracted from Instrumentation module.

Workflow of data transfer from Instrumentation module to Electrical module is shown in Fig.3.
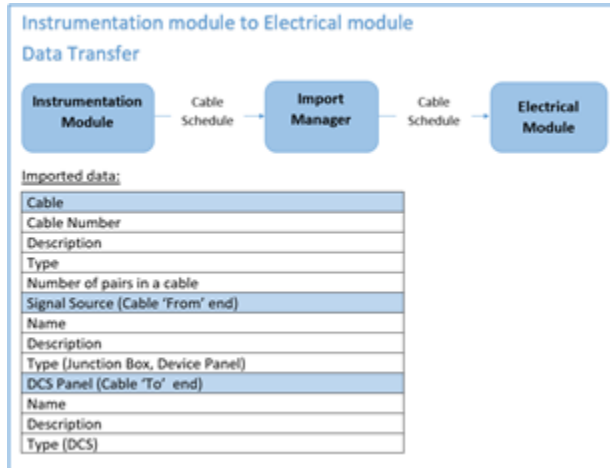

Fig. 2:Data transfer from Instrumentation to Electrical module

This import process created all signal sources, DCS panels and Instrumentation cables in Electrical module. The correlation between the objects retained in Electrical module. The cable schedule imported in Electrical module was similar to the cable schedule in Instrumentation module with the added information of electrical switchgears or electrical MCC connected to each signal source.

Cable properties with 'From' end and 'To' end details in Electrical module are shown in Fig.4 and cable schedule in Electrical module is shown in Fig.5
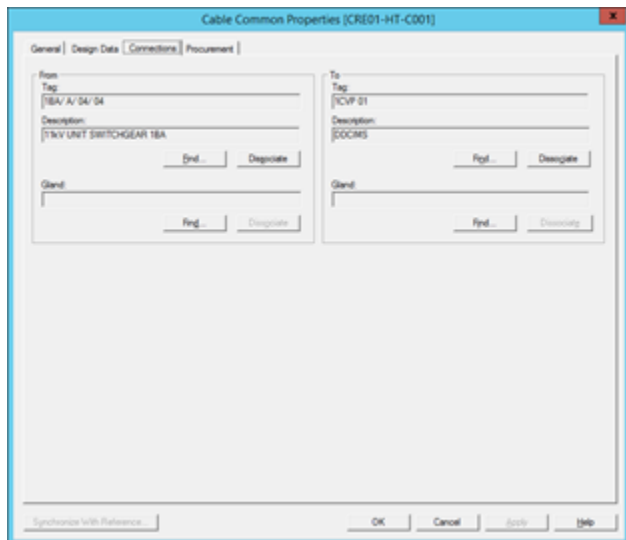

Fig. 3:Cable association with 'From' end and 'To' end in Electrical module

Cable Schedule							
Cable Tag	Cable Category	Cable Specification	Cable Type	From Panel Description	From Panel module no.	To Panel	To Description
CRE01-HT-C001	Instrumentation	8P X 0.5 MM² MULTIPAIR TWISTED G-TYPE (OS)	Signal	11kV UNIT SWITCHGEAR 1BA	4	1CVP 01	DDCIMS
CRE01-HT-C002	Instrumentation	2P X 0.5 MM² MULTIPAIR TWISTED F-TYPE (IOS)	Signal	11kV UNIT SWITCHGEAR 1BA	4	1CVP 01	DDCIMS

Fig. 4:Cable schedule extracted from Electrical module

Detailed specifications of Instrumentation cables were created in Electrical module. The detailed specification mainly consists the information such as cable conductor type, material used, cable diameter size, cable weight. The detailed specifications for cables are required to calculate the cable trays loading, space availability in trays in 3D module. These specifications were assigned to Instrumentation cables. Added information to Instrumentation cable like conductor size, type, material, insulation is shown in Fig.6
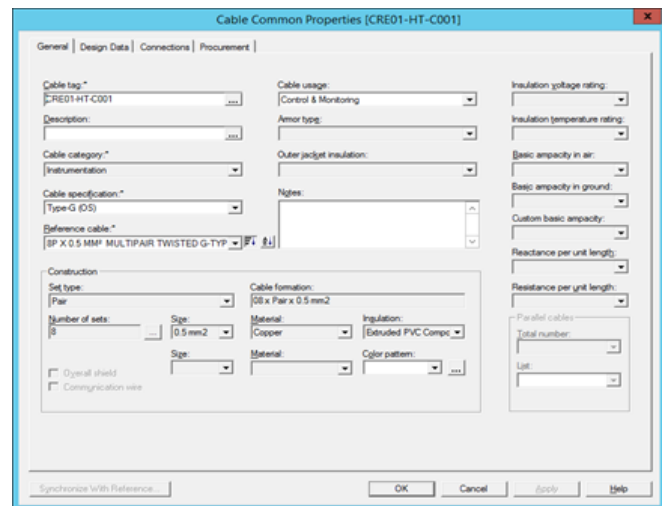

Fig. 5:Assigning detailed specification to Cable in Electrical module

The cable schedule, thus updated, was extracted from Electrical module and published to Foundation module and retrieved into 3D module. Workflow of data transfer from Electrical module to 3D module is shown in Fig.7 and cable schedule after retrieving in 3D module is shown in Fig.8.
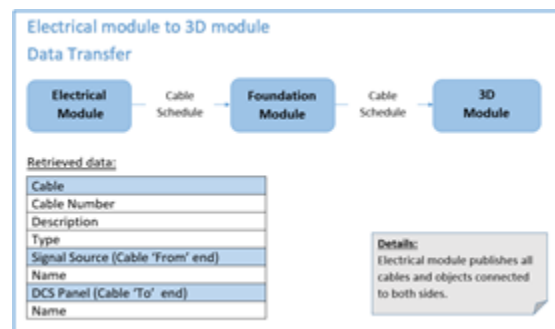

Fig. 6:Data transfer from Electrical module to 3D module

Fig. 7: Cable schedule retrieved in 3D module

Step-3: 3D Modeling- In 3D module, for the project, cable trays network was available as the part of power plant 3D modeling. In the cable trays network, cable trays were identified for Instrumentation cables as per the cable trays layout drawings. In 3D module, for cable routing it is mandatory for all cable trays not to have any 'physical' or logical gaps else routing of cables does not take place. So as a device to facilitate the change-over of cables from one tray to another at intersections or otherwise, logical connections at the trays crossings were made across the cable tray network to achieve a fully connected network. This continuously connected cable tray network is required only when cable routing is being done in 3D module. To achieve this consistency, segmentation of cable trays was done to trace the gaps and to locate missing connections between cable trays.

Rules and constraints like cable trays fill efficiency, signal type were applied on the cable trays network to identify the cable trays for Instrumentation cables. The property window of cableways with cable trays fill efficiency and signal type is shown in Fig.9.

Fig. 8:Constraints applied on cable trays in 3D module

After the identification of cable trays for Instrumentation cables, a view of cable trays network in 3D module is shown in Fig.10 where Blue coloured cable trays are for Power cables and Yellow coloured cable trays are for Instrumentation cables. Electrical switchgears and DCS panels are shown in the figure in Green and Orange colours respectively.
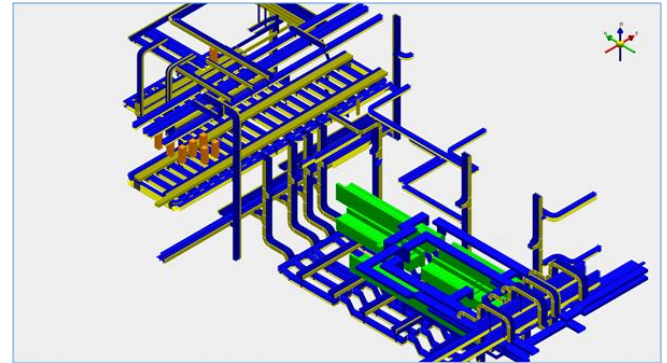
Fig. 10: Cable Tray Network, Electrical Switchgears and DCS Panels in 3D module

Then, routing of cables was done in 3D module in auto-routing mode. Auto-routing mode suggests the shortest routing path for all the selected cables based on rules and constraints on cable tray network. The available auto-routing options for cables in 3D module are shown in Fig.11.

Fig. 11: Cable Routing options in 3D module

Routing of Instrumentation cables in 3D module from electrical switchgear to DCS is shown in Fig.12 and Fig.13.

Fig. 12: Routed Instrumentation cables from Switchgear to DCS panel in 3D module (Plan View)

Fig. 13: Routed Instrumentation cable from Switchgear to DCS panel in 3D module (Isometric View)

Fig. 14: Data transfer from 3D module to Electrical module

Electrical module fetched the routed cable length and cable routing path from cable schedule when retrieved from 3D module. Routed cable length and cable routing path under cable properties is shown in Fig.15

Fig. 15: Cable in Electrical module with Routing Length and Routing Path after retrieving data from 3D module

Cable schedule was extracted from Electrical module in spreadsheet format, shown in Fig.16.

Cable Number	Cable type	From End Panel Name & Type	From End Panel No.	To End Panel No.	To End Panel Type	Cable Routed Length	Cable Routing Path
CRE01-HT-C001	8P X 0.5 MM² MULTIPAIR TWISTED G-TYPE(OS)	11kV UNIT SWITCHGEAR 1BA	4	1CVP 01	DDCIMS	67.01 m	MA75L04;MA75_34;MA34L04;MA33L04;MA33L04;MA33L04;MA33L04;MA33L04;MA33L04;MA33L04;MA33L04;MA31L04;MH02L04;MA31L04;MA53_31;MA53L04;MA53L04;MA53L04;MA53L04;MA52L04;MA52L04;MA52_RC02;RC02L05;RC02L05;RC02L05;RC02L05;RC02L05;RC02L05;RC02L05;RC02L05;ILV001;ILV001-TRAY-0201;CCR1_ILV001;Unspecified;Unspecified;CR42_CCR1;CR47_L2_L;Cableway-2083207809;V4;

Fig. 16: Cable Schedule extracted from Electrical module with routed cable information

This cable schedule now has the added information of routed cable length and cable routing path; cable trays fill percentage as compared to previously available information.

Finally, the updated cable schedule, extracted from Electrical module, was imported back to the Instrumentation module for completing the cycle. Workflow of data transfer from Electrical module to Instrumentation module is shown in Fig.17.

Fig. 17: Data transfer from Electrical to Instrumentation module

6. Comparison of output of 3D software routed cables with 2D software routed cables

The routed cable paths from electrical switchgear to DCS panels were traced on the layout drawings and compared with the routed cable path generated by legacy method using in-house developed 2D software, it was found that the cables routed in 3D module take the similar path as routed by 2D software but the routed cable length extracted from 3D is generally less than the routed cable length extracted from 2D software. Approximately 36% cable length difference is observed for one cable schedule, having 33 cables which were routed from electrical switchgears to DCS panels.

On analysing the differences, it is found that in 2D software, cables were not getting routed upto switchgear and DCS panel ends. Cables were running only in cable trays, hence specific cable length for each terminating end was added in the routed cable length. This additional length was added to every cable in the schedule. Similarly, in

the routed path of the cable, for each turn in the cable trays, 1mtr additional length was considered and was added to the routed cable length. Whereas in 3D module, cables were routing upto terminating ends and additional cable length at turns was not taken.

7. Benefits

Routing of cables in 3D model creates the replica of site on a digital platform. Hence, it can be helpful to the site person to visualise the route of the cables before laying them down in physical. It will also benefit BHEL to hand over the digital plant to customer in future. There can be other hitherto unrevealed benefits from the digitization of cable-routing process, which will emerge if the practice of 3D cable routing is established.

8. Issues faced and Learnings

Certain technical issues related to software were encountered and addressed during the process. These issues are listed below:

i. When publishing and retrieving the cable schedule between Electrical module and 3D module, mapping of types of signal sources (Junction Box, Device Panel), and electrical switchgears was missing in Foundation module.
Signal source devices and electrical switchgears in Foundation module were identified and mapped with the Electrical module signal source devices and electrical switchgears and 3D module signal source devices and electrical switchgears. These mappings enabled publishing and retrieving of cable schedules between Electrical module and 3D module.

ii. While retrieving the cable schedule in 3D module, cables were not getting created. It was happening due to the missing or mismatched naming of signal sources, switchgears and DCS panels in 3D module. Signal source, switchgears and DCS panel names should be exactly the same as available in cable schedule, else cables do not get created in 3D module from cable schedule when retrieving from Electrical module.
Naming of all signal sources, switchgears and DCS panels was checked and corrected in 3D module. Now when cable schedule was retrieved in 3D module, it auto-correlated the cable schedule data with 3D module data and created all cables automatically in 3D module.

Further, it is noted that on completion of routing of cables, names of cable trays reflect in cable routing path field of cable schedule, hence naming of cable trays should also be done correctly & logically.

iii. At the time of making logical connection between cables trays for enabling the routing of cables in 3D module, it was found that cable trays network was not created as per tier-wise cableways philosophy. Cable trays in power plant are always laid down in tiers for keeping the Power cables and Instrumentation cables separate. In 3D module, cable trays were modelled area wise but for different tiers of one segment of cable tray, separate cableways were not created. Common cableway for multiple tiers of one or more than one cable trays does not affect the modeling behaviour of cable trays, but when cable trays were being identified for Instrumentation cables and were needed to interconnect logically for routing of cables, the requirement of separate cableways for each tier was identified.
Cable trays were separated in cableways for individual tier of cable trays as per the requirement of 3D module. It also sped up the creation of logical connections between cable trays and in more correct manner.

iv. As discussed previously, in 3D module, for routing of cables, cable trays network should be free from any physical or logical gaps in between, else routing of cables does not take place. Gaps identification between cable trays was one major task and creating logical connection at various cable trays crossing was another big task. These connections do not exist in reality in power plant, hence a wrong connection can lead to the incorrect routing of cables by giving an alternative path to cables which in-reality does not exist and should not be an option.
Logical and physical gaps were identified and corrected in the complete cable tray network.

v. When analysing the data after routing the cables in 3D module, it is found that two cables which signal sources and DCS panels were same, were taking the different paths. On further analysis, it was identified that one of cable was routed when all Instrumentation Signal trays were empty and it took shortest path. Another cable was being routed later

when some of cable trays of the other cable path got occupied, hence this cable took the different and lengthier path.

To correct the routing of cables, cables were routed en- masse so that each cable got the equal opportunity to find the best shortest path because on meeting the cable tray fill efficiency constraints, remaining cables started taking the next available shortest path.

vi. After completing the routing of cables, some cable trays were modified in 3D module by cable tray layout engineer. Hence, many of the cables which were passing from these modified cable trays, became 'incomplete' in routing status. So when cable schedule was published from 3D module to Electrical module, routed cable paths of many cables were not appearing in the cable schedule which was extracted from Electrical module.

To deal with the issue, all the cables were re-

Table 1:List of Team Members and their roles

routed after freezing the cable tray network, otherwise chance to choose the shortest path by the concern cables might have not been available as maximum number of cables trays were already filled. It was decided that modification in cable trays network after laying down the cables in 3D module should be avoided or cable routing shall be done once cable trays network is frozen.

9. Conclusion

A new methodology is established to route Instrumentation cables in 3D using integration interfaces available between different Engineering modules of SmartPlant and graphical representation of routed path of cables in 3-dimensions became possible. Such output can help site personnel in visualising the information provided in a value-added manner.

Modeling of cables in 3D module will be a logical step toward more comprehensive and inclusive plant modeling.

10. Team involved in the work

In this project, subject matters experts and skilled people from respective domains were involved. The domains are:

- Instrumentation Engineering
- Electrical Engineering
- SmartPlant software administration and customisation

- 3D modeling

Hence, a team of nine people was formed. Their names, roles with their subject matter expertise are listed below:

S.No.	Name	Designation	Roles & Expertise
1	Smt. Neha Sharma	Deputy Manager	Project Leader, SmartPlant Instrumentation Software Administrator and Customisation expert
2	Sh. Rajeev Tivari	Senior Deputy General manager	Project Manager
3	Sh. Awesh Kumar	Manager	SmartPlant Electrical, SmartPlant Foundation Software Administrator and Customisation expert
4	Sh. Naishadh Pushkaran	Senior Engineer	SmartPlant Electrical, SmartPlant 3D software Administrator and Cable Catalogue creation
5	Sh. Ranvir Singh	Manager	SmartPlant 3D model expert and Completion of Cable Tray network in 3D module
6	Smt. Gunjal Verma	Deputy Manager	SmartPlant 3D model expert and Completion of Cable Tray network in SmartPlant 3D software
7	Sh. Jai Kant Gautam	Manager	Instrumentation Engineering, modeling of filed signal sources and routing of Instrumentation Cables from DCS to fields in SmartPlant 3D software
8	Sh. Krishan Kumar Meena	Deputy Manager	Instrumentation Engineering, modeling of filed signal sources and routing of Instrumentation Cables from DCS to fields in SmartPlant 3D software
9	Sh. Ankur	Deputy Engineer	Electrical Engineering, modeling of Switchgears and MCC in SmartPlant 3D software

Special guidance and support throughout the project execution was provided by following senior members of the division are:

S.No.	Name	Designation
1	Sh. KK Khurana	Executive Director BHEL-PEM (Retd.)
2	Sh. Jacob James	General Manager - Mechanical Piping Layout, Integrated Plant Design System, Power Plant Development Cell and Digital

		Transformation Group BHEL-PEM (Retd.)
3	Sh. Anil Joshi	Executive Director BHEL-PEM
4	Sh. Debasisa Rath	Additional General Manager- Electrical Engineering Department BHEL-PEM

Table 2:List of senior members and supporters

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