

## 발전소 케이블 포설에서 Raceway의 유연한 케이블 Fill 체크 기반 자동화된 케이블 라우팅 설계

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### Automated Cable Route Design based Flexible Cable Fill Check of Raceway in Cable Spreading of Generating Station

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#### 요 약

발전소 설비에서 케이블 포설을 위한 설계는 발전소 설비에 사용되어지는 케이블 유형의 다양한 형태로 인해 매우 많은 시간이 요구되고 매우 중요한 과제이다. 케이블 포설 설계 시 레이스웨이(Raceway)는 출발지(Source) 장비로부터 목적지(Destination) 장비까지의 케이블 트레이(Tray) 및 콘duit(Conduit)의 포설 구간을 의미한다. 기존의 케이블 포설 설계 과정은 모두 수기에 의해 작성되어 인적/시간적 투자손실이 크고, 케이블의 누락 및 케이블 오버필(Over Fill)과 같은 비효율적인 손실이 빈번히 발생한다. 따라서 본 논문에서는 효과적인 발전소 케이블 포설 설계를 위한 레이스웨이의 유연한 케이블 오버 필(Fill) 체크 기반의 자동화된 케이블 라우팅 경로 계산 알고리즘을 구현하였고, 제안한 자동화 케이블 라우팅 설계기법은 케이블 위치의 변화에도 유연한 레이스웨이 계산이 가능하다. 구현 결과, 케이블 라우팅 설계 프로그램은 발전소 케이블 포설 설계 사양을 준수하면서 케이블 라우팅 경로를 효과적으로 설정하고, 케이블 포설 설계 시간을 기존 대비 크게 단축하는 성능을 얻을 수 있었다.

#### ABSTRACT

In generating station, cable spreading design is a very important task, which is very much time consuming, due to the type of cable used in generating station is very diverse. The raceway means the cable line section from source equipment to destination, and consists of cable tray and conduit. The process of existing cable spreading design was written in by hand. Thereby, there are grossly inefficient gain such as cable omission and unfixed fill value by a personal and time investment. In this paper, we proposed and implemented the automated cable route design based flexible cable fill check in generating station, and proposed the automated cable route design can be calculated the cable fill with flexible changing of raceway. Some experimental result shows that implemented cable route design is well performed and conducted as the design specifications, and it will be able to reduce the cable spreading design time.

**키워드** : 케이블 포설, 케이블 필, 레이스웨이 구성, 콘duit, 케이블 트레이

**Key word** : Cable spreading, Cable fill, Raceway configuration, Conduit, Cable tray

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## I. INTRODUCTION

Recently, a number of generating station construction projects around the world has been proceeding for securing energy. Effective cable spreading design in generating station construction is a very important task without the redesign and design errors. The type of cable has at least 40,000 or more due to the characteristics of the electrical installation engineering, and raceway types such as conduit and tray also vary [1-3]. However, the design of the electrical installations for generating station construction is still carried out by hand, so it has personal and temporal investments inefficiency. In particular, the conventional electrical installation design is time consuming at least six months or more depend on design scale, and it may also entail unnecessary error such as cable omission, cable shortage and more than the reference value with unfixed cable fill. Therefore, the automation of cable spreading design, including cable systems, raceway types, cable fill and cable drum schedules, is a very important process for effective cable spreading design without errors that can occur frequently. This process should be implemented with a function which allows the designer to perform raceway cable fill calculation effectively. In addition, the designer must have access to the raceway and cable information, and this should be easy to modify to minimize design errors.

In order to effectively automate the cable installation, we proposed and implemented the cable installation program which can be done cable spreading plan for generating station construction. Proposed the cable installation automation, which is coded the raceway and cable, can calculate the cable fill, raceway route and optimal scheduling of the cable drum.

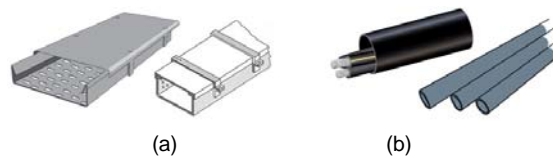
The paper was organized as follows. Section 2 describes the concept of raceway route and raceway code design, Section 2 was devoted to the cable code definition and the design. Section 4 discusses the cable fill calculation, and Section 5 presents the result of the design of cable drum schedule. The final section is

devoted to conclusion and pointing to some further issues.

## II. Raceway Configuration

### 2.1. Raceway Definitions

Raceway systems consist primarily of cable tray and conduit [4]. Cable trays are used as an alternative to open, and are commonly used for cable management in commercial and industrial construction. As shown in figure 1, a cable tray system is also used to support insulated electric cables used for power distribution or communication, and an electrical conduit is a tube used to protect and route electrical wiring in the electrical wiring of buildings.



**Fig. 1** The types of raceway system (a) cable tray (b) conduit

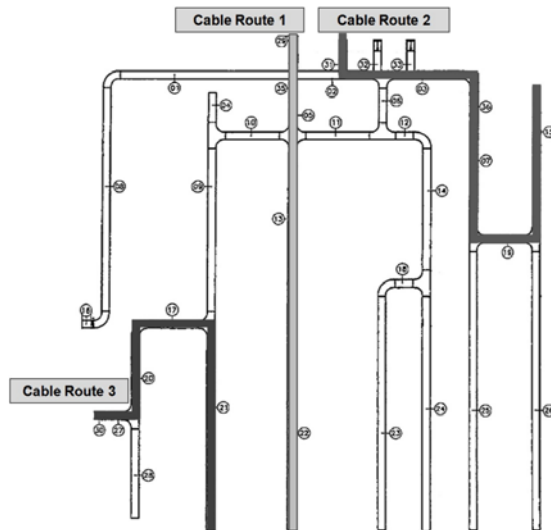
Raceway should be adequately sized as determined by the maximum recommended percentage fill of the raceway area, which is explained in more detail in Section 5. The raceway means the cable line section from source equipment to destination. Figure 2 shows the concept of raceway which is installed cables depending on the type of raceway, and the outline of cable routes are given below.

- **Cable route 1:** 29 → 35 → 5 → 13 → 22.
- **Cable route 2:** 31 → 2 → 3 → 36 → 7 → 19 → 15.
- **Cable route 3:** 30 → 27 → 20 → 17 → 21.

Cable route 1 and route 2, for example, consists of four and six cable line section, respectively. If the cable line section 5 and 35 is more than the maximum recommended fill in cable route 1, it must be installed to

bypass the cable as shown below.

- **Cable route 1(bypass installed):** 29 → 2 → 6 → 11 → 13 → 22.



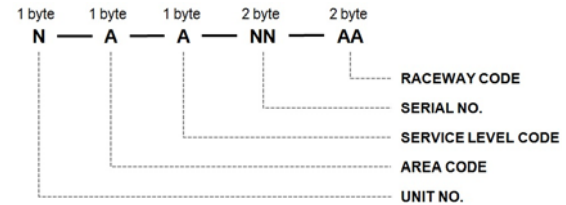
**Fig. 2** The concept of raceway for cable installation in generation system

## 2.2. Raceway Code Design

In this paper, we designed the raceway code which consists of unit, area, service level, raceway type and serial as figure 3. The unit code means the plant type such as hydroelectric, thermoelectric, gas turbine and nuclear power plant. The area code, small classification of the unit, presents the locations including control building, gas turbine generator (GTG), steam turbine, heat recovery steam generator (HRSG), cooling tower, and so on. The service level code of figure 3 is cable circuit classifications, and is designed to supply power to utilization devices of a plant auxiliary system. The serial code was added as extra purposes of design management. Finally, raceway code is designed with the following configuration, and it can be redefined differently depending on the type of power plant.

- HOT DIP GALVANIZED CONDUIT.
- RIGID POLYVINYL CHLORIDE THIN PIPE.

- UNPLASTICIZED POLYVINYL CHLORIDE CONDUIT.
- GALVANIZED STEEL TRAY.



**Fig. 3** Raceway code derivations

Table 1 shows the design information of unit and area code. Code information presented in table 2 through 4 is service level code, serial code and raceway code. If the raceway code '2GK01TD' defined based on figure 3, it means a galvanized steel tray which is the size of 100×450mm, and this tray is installed in the gas turbine room of GTG building.

**Table. 1** Unit and area code

Unit	Description	Area	Description
0	COMMON	C	CONTROL BUILDING
1	GTG#1	G	GAS TURBINE
2	GTG#2	H	HRSG. AREA
3	BOP	S	STEAM TURBINE
-	-	T	COOLING TOWER

**Table. 2** Service level code

Service Level	Description
A	345kV CABLES
B	154kV CABLES
C	6.9kV CABLES
H	480V LOAD CENTER CABLES
K	480V POWER FROM MOTOR CONTROL CENTER
L~N	AC AND DC CONTROL (220V, 110V AC/125V, 24V DC)
X~Z	INSTRUMENTATION AND ANALOG COMPUTER INPUT

**Table. 3** Serial No. code

Serial No.	Description
01	FOR TEST
02	SERIAL NO.

**Table. 4** Raceway code

Category	Raceway No.	Description	Baseline of fill(%)
HOT DIP GALVANIZED CONDUIT	RA	22mm	-
	RB	28mm	-
	RC	36mm	-
	RD	42mm	-
	RE	54mm	-
	RF	70mm	-
	RG	82mm	-
	RJ	104mm	-
	RK	125mm	-
RIGID POLYVINYL CHLORIDE THIN PIPE	RL	150mm	-
	DK	125mm	-
	DL	150mm	-
UNPLASTICIZED POLYVINYL CHLORIDE CONDUIT	DM	200mm	-
	PA	22mm	-
	PB	28mm	-
	PC	36mm	-
	PD	42mm	-
	PE	54mm	-
	PF	70mm	-
	PG	82mm	-
GALVANIZED STEEL TRAY (LADDER)	PH	104mm	-
	TA	100×150	40
	TB	100×200	40
	TC	100×300	40
	TD	100×450	40
	TE	100×600	40
	TF	150×150	40
	TG	150×300	40
	TH	150×450	40
	TJ	150×600	40
	TK	150×750	40
GALVANIZED STEEL TRAY (SOLID BOTTOM)	TL	100×750	40
	TS	150×150	30
	TT	150×200	30
	TU	150×300	30
	TV	150×450	30
	TW	150×600	30
	TX	150×750	30

### III. Cable Code System

This section establishes the cable code information that shall be utilized in specifying cables. Cables shall

have a qualified life for all service conditions that are postulated for the areas where they are to be used and shall be qualified in accordance with IEEE standard 323-1983 and ANSI/IEEE standard 383-1974 [5].

#### 3.1. Cable Circuit Classifications

Cable selection should be considered in the selection of cable for installation in power generating stations. In [5], the recommendation for cable circuit classifications has been presented.

#### 3.2. Cable Code Design

A balance of cable characteristics method to the environmental conditions of the power plant is very important due to section 3.1. Depending on the plant type, installation site and purposes, cable selection can vary, but most cable characteristics can be of a cable type, the number of conductors and the size of conductors as in figure 4.

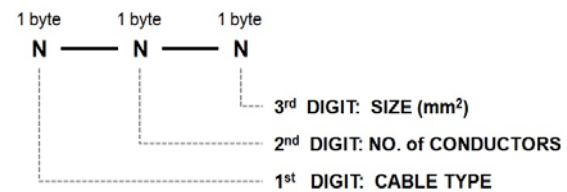
**Fig. 4** Cable code derivations

Table 5 shows the designed cable code, and was designed based on figure 4. Assuming that the cable code is '848', this means the power cable rated 345kV to less with four conductors and an conductor size 4  $mm^2$ , and the cable code can be configured in various ways as follows. Table 4 shows the example of designed cable code.

- Cable code '848': power cable, 0.6/1kV 4C×4 $mm^2$ .
- Cable code '1BL': power cable, 345kV 15C×240 $mm^2$ .
- Cable code 'A39': control cable, 0.6/1kV 3C×6 $mm^2$ .
- Cable code 'D4B': instrument cable, 0.6/1kV 4C×10 $mm^2$ .

**Table. 5** The example of cable code design

Code No.	1 <sup>st</sup> DIGIT	2 <sup>nd</sup> DIGIT	3 <sup>rd</sup> DIGIT
	Type	No. of conductors	Size (mm <sup>2</sup> )
1	345 kV POWER CABLE	1 / C	-
2	-	2 / C	-
3	-	3 / C	-
4	6/10 kV POWER CABLE	4 / C	0.5
5	-	5 / C	-
6	-	6 / C	1.5
7	-	7 / C	2.5
8	0.6/1 kV POWER CABLE	8 / C	4.0
9	-	10 / C	6.0
A	0.6/1 kV Control Cable	12 / C	-
B	0.6/1 kV Control Cable HI TEMP	15 / C	10
C	0.6/1 kV Shielded Control Cable	20 / C	16
D	0.6/1 kV Instrument Cable	30 / C	25
E	-	1 PR	35
F	Thermocouple CHROMEL-ALUMEL	2 PR	-
G	Thermocouple CHROMEL-CONSTANTAN	3 PR	70
⋮	⋮	⋮	⋮

## IV. Raceway Cable Fill Calculation

### 4.1. Raceway Cable Fill Requirements

This section establishes requirements for the construction methods and materials for the handling and installation of cable systems. As of 1984 IEEE standard 690-1984 [5], *IEEE standard for the design and installation of cable systems for class 1E circuits in nuclear power generating stations*, is completed and is being validated by commercial and industrial construction. In the reference [6], the raceway cable fills recommendations as follows.

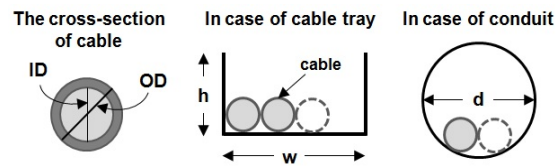
- The number of cables in any tray or conduit shall be limited by cable ampacity requirements.
- A cable tray filled to the predetermined quantity (design limit) shall not be used for further cable routes, unless an inspection or an analysis has been made that indicates additional cables can be installed.
- An analysis shall be made to determine the range of

weight of cable loading and this figure shall be used in the seismic analysis of the cable-tray support system. These loadings shall not be exceeded by placing more cables in the tray than allowed by the seismic design.

- Conduit fill shall be in accordance with ANSI/NEPA-70-1984, unless an analysis has been made that indicates that additional cables can be installed.

### 4.2 Automation of Cable Fill Calculation

This section describes the process of raceway cable fill calculations in case of cable tray and conduit. Figure 5 shows the cross-section of cable and the concept of cable tray and conduit, and outside diameter (OD) is used to calculate fill in the cross-section of cable. The sum of area (SoA) means the cross-sectional area (CSA) of cable tray or conduit, and an area of cable (AoC) is a cross-sectional of a cable as in formula (1).



**Fig. 5** The cross-section of cable, and the structure of cable tray and conduit

$$CSA = 100 \times \sum_{n=1}^N AoC_n, \quad AoC = \frac{\pi \times OD^2}{4}. \quad (1)$$

Raceway cable fill, for example, summation of the cable cross-sectional area, in random filled cable trays should be limited in design to a predetermined percentage of cable tray usable cross-sectional area. A percentage fill limit is needed for random filled trays because cables are not laid in neat rows and secured in place. This results in cable crossing and void areas which take up much of the tray cross-sectional area. Generally, a 30% to 40% fill for power and control cable and 40% to 50% for instrumentation cables will result in a tray loading so that no cable will be installed above the top of the side rails of the cable tray except as necessary at intersections and where cables enter or exit

the cable tray systems [6-8]. If two cables '838' and '83C' are installed in raceway '2GK09TD' and the cable OD value is given as shown in table 6, raceway cable fill is calculated as follows.

- An area of raceway code 'TD' is  $45,000\text{mm}^2$  ( $100 \times 450\text{mm}$ , as shown in table 4) and the baseline of fill is 40%, therefore SoA is  $18,000\text{mm}^2$ .
- Since OD of cable code '838' is  $14\text{mm}$ , AoC of cable code '838' is  $154\text{mm}^2$ . Likewise, AoC of cable code '83C' is  $425\text{mm}^2$  with cable OD size of  $23\text{mm}$ .
- The CSA of two cables in raceway '2GK09TD' is accounted for 4.22% of SoA capacity.

**Table. 6** An area of cable according to cable OD value

Cable Code	Cable OD(mm)	AoC( $\pi/4 \times OD^2$ )
838	14.0	154
83A	17.0	227
83B	19.5	299
83C	23.0	415
⋮	⋮	⋮

In case of conduit, because of conduits and tubing from different manufacturers have different internal diameters for the same trade size, Table 7 shows the diameter and the actual area of different raceway for 31, 40, and 53 percent fill [7].

**Table. 7** Percentage of cross section of conduit and tubing for conductors

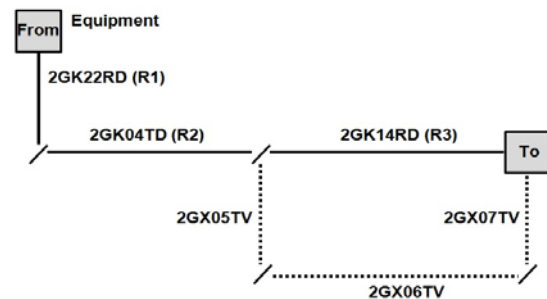
Number of Conductors	All Conductor Types
1	53 %
2	31 %
Over 2	40 %

Table 7 is based on common conditions of proper cabling and alignment of conductors. It should be recognized that, for certain conditions, a larger size or a lesser conduit fill should be considered. Table 8 shows the percentage of conduit fill depending on cable OD and the number of its conductors.

**Table. 8** The baseline of fill for conduit according to the number of cables

Cable OD (mm)	AoC ( $\pi/4 \times OD^2$ )	Fill of a Cable (53%)	Fill of Two Cables (31%)	Fill of Three Cables (40%)
22	380	201	118	152
36	1,018	539	316	407
104	8,495	4,502	2,633	3,398
⋮	⋮	⋮	⋮	⋮

Let's assume that cable code '83A' is spread in the raceway as shown in Figure 6 and 7.



**Fig. 6** Example of installation path (R1, R2 and R3) of cable code '83A'

Raceway Code	Raceway Name	Raceway Size	Raceway Fill	Raceway Status
R01	2GK22RD	30.91%	30.91%	OK
R02	2GK04TD	57.48%	57.48%	OK
R03	2GK14RD	149.59% (OF)	149.59% (OF)	OF

**Fig. 7** Cable route information of cable code '83A' including fill of each raceway

In Figure 6 and 7, the cable code '83A' has been laid to sequentially 2GK22RD (R1), 2GK04TD (R2) and 2GK14RD (R3). This code is constituted by 7 bytes, and the last two bytes are raceway code as shown in Figure 3. The raceway code are also described in Table 4, 'RD' and 'TD' code has the following information.

- RD: HOT DIP GALVANIZED CONDUIT having a diameter '42mm'.
- TD: GALVANIZED TRAY having a height '100mm'



and a width '450mm'.

In Figure 8, the raceway '2GK14RD' has a 149.6%, and it is a case of exceeding the baseline percent depending on the number of cable. Therefore, the cable '83A' must be spread by bypassing the other raceway, and Figure 9 shows the cable passing including cable '83C' and '83A' through the raceway '2GK14RD'. By the cable '83A' is laid to bypass from raceway '2GK14RD' to '2GX05TV', the cable fill of raceway '2GK14RD' has become from 149.6% to 56.6% as shown in Figure 10. The cable fill of raceway '2GK14RD', cable spreading before and after bypassing, is as follows.

- Before bypassing (two cable):  $(415mm^2 + 227mm^2) / 429mm^2 \times 100(\%) = 149.6\%$ .
- After bypassing (a cable):  $415mm^2 / 734mm^2 \times 100(\%) = 56.6\%$ .

The cable OD values of cable code '83C' and '83A' are 23 and 17mm as shown in Table 6, and each cable have AoC values of 415 and 227mm<sup>2</sup>, respectively. Also, 429 and 734mm<sup>2</sup>, percent of cable fill, means the

baseline of fill for conduit according to the number of cables as shown in Table 7 and 8.

NO	CABLE_NUMB	TYPE_CODE	Volt(KV)	Size	Cable O.D	Length(M)	Cable Route
7	5-35410-C...	83C	0.6/1kV	FR-CV 3C/25+(16)	23.0	250	2GK13RD, 2GK04TD, 2GK14RD
8	5-36620-C...	83A	0.6/1kV	FR-CV 3C/10+(10)	17.0	250	2GK22RD, 2GK04TD, 2GK14RD

RACEWAY	Sum of Area(EF)...	FR(%)	Cable Q'ty	Cable N°
2GK11RA	153.94/201.47	76.41%	1	1
2GK01TD	9967.91/20000.00	49.94%	15	1,3,4,5
2GK02TD	9760.93/20000.00	48.80%	14	1,3,4,5
2GK05RA	176.71/201.47	87.71%	1	2
2GK06RA	176.71/201.47	87.71%	1	2
2GK07RA	226.98/201.47	112.66% (OF)	1	3
2GK01RA	153.94/201.47	76.41%	1	4
2GK03TD	1643.43/20000.00	82.07%	19	4,5,16
2GK11RC	1284.91/407.15	315.59% (OF)	4	5,6,33
2GK13RD	1007.93/254.18	190.90% (OF)	3	7,35,36
2GK04TD	11495.09/20000.00	57.48%	14	7,8,17
2GK14RD	642.46/429.49	149.59% (OF)	2	7,8
2GX05TV	354.68/734.36	50.01%	1	8

Fig. 8 Cable passing through the raceway '2GK14RD'

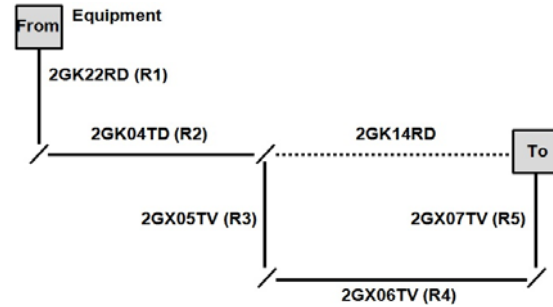


Fig. 10 Final installation path (R1, R2, R3, R4 and R5) of cable code '83A'

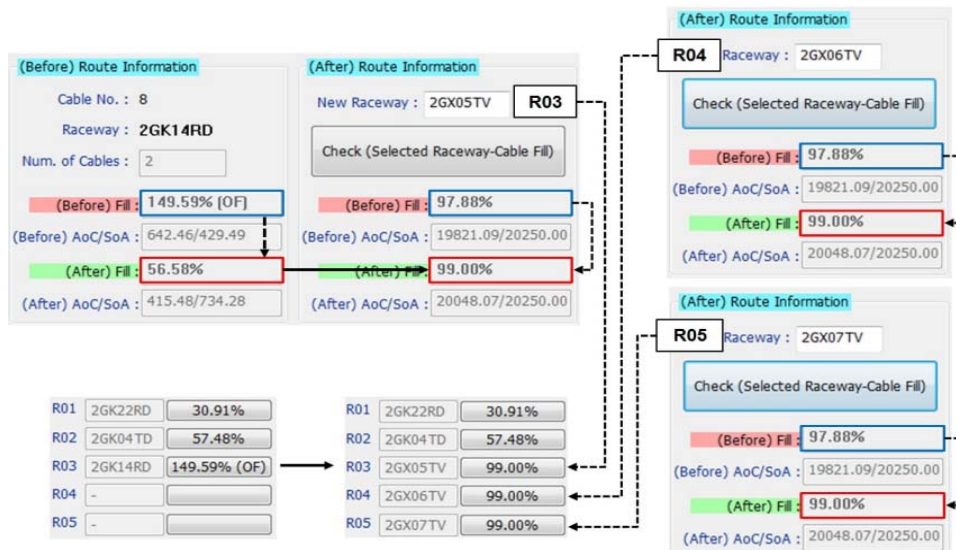


Fig. 9 Cable spreading process by bypassing cable '83A' to other raceway

As shown in Figure 9, cable fill of raceway '2GK14RD' has been changed from 149.6% to 56.6%, due to cable '83A' is bypassed from raceway '2GK14RD' to '2GX05TV'. Figure 10 shows the cable routes of cable '83A' before and after bypassing to other raceway.

## V. CONCLUSION

Effective cable installation design is required for electrical equipment in generating station. This task is complex and too much time may be invested in designing them. The existing cable spreading design was proceeded in by hand, thus there are some inefficient gain by a personal and time investment. Therefore, the method of automated cable spreading design is necessary for reducing cable omission and unfixed cable fill value. In this paper, we proposed and implemented the automated cable route design with flexible cable fill check. Cable fill should be calculated in a different way depending on the type of raceway, which means the cable line section from source equipment to destination. Experimental result shows that implemented cable route design is well performed and conducted as the design specifications, and it will be able to reduce the cable spreading design time.

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