COMPARISON OF ELECTRIC SUB-STATIONS FROM THE RELIABILITY POINT OF VIEW

By

S. S. PINGLE

Department of Electrical Power Engineering, Technical University, Budapest

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Presented by Prof. Dr. O. P. GESZTI

1. Consumers nowadays have become reliability conscious and every electric supply undertaking has to see that a reliable supply is given to its consumers. Sub-station is one of the important parts of the electric supply network. Every sub-station has got a number of incoming and outgoing lines. This number depends upon the load, the peak, etc. There is typical arrangement of circuit-breakers, isolating switches etc. both for the incoming and outgoing lines. Sub-stations are classified on this basis and are called single bus-bar type, double bus-bar type etc. The main question is how far these arrangements are good from the reliability point of view so that we can grade them from the reliability considerations and ultimately choose one which would satisfy our requirements both from the financial and reliability points of view. The reliability of the supply to the consumer would depend upon the total number of incoming and outgoing lines in the sub-station. However, it would be interesting to find out the reliability offered by one set of incoming and outgoing line. Such set of one incoming and one outgoing line can be termed as one "way". On the basis of the reliability of one way of each type of sub-station can be based the general comparison of the sub-stations. The notations used are:

	Reliability	Unreliability
Bus-bar	R_B	Q_B
Isolating switch	R_S	Q_S
Circuit-breaker	R_C	Q_C

2. On the basis of the above-mentioned considerations, calculations can be performed for the different types of schemes normally used in practice.

2.1. *Single bus-bar type*

The connection diagram and the reliability block diagram are shown in Figs 1 and 2.

The Boolean tr insmission function can be written as:

$$T = A \cap Y \cap B \cap C \cap Z \cap D \cap S$$

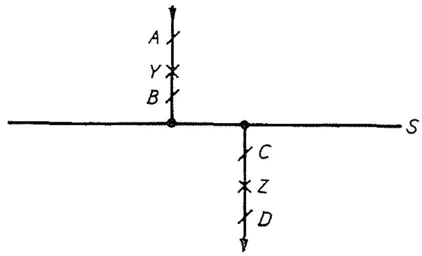

Fig. 1

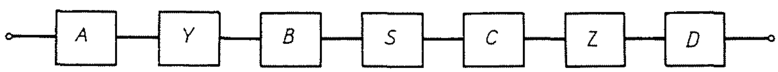

Fig. 2

The probability for a reliable operation would be:

$$P(T) = R = P\,(A \cap Y \cap B \cap C \cap Z \cap D \cap S)$$
$$= R_S^4\, R_C^2\, R_B\,. \qquad (1)$$

2.2. *Double bus-bar single breaker type sub-station*

Here we have to consider all the possible paths which lead the current from the receiving end to the sending end. The connection diagram and reliability block diagram are shown in Figs 3 and 4. Due to the presence of the two bus-bars and the bus-coupler, there are four possible paths.

Path I $A \cap X \cap B \cap S_1 \cap E \cap Y \cap H$

Path II $A \cap X \cap C \cap S_2 \cap D \cap Y \cap H$

Path III $A \cap X \cap B \cap S_1 \cap F \cap Z \cap G \cap S_2 \cap D \cap Y \cap H$

Path IV $A \cap X \cap C \cap S_2 \cap G \cap Z \cap F \cap S_1 \cap E \cap Y \cap H$

It is noticed that between AX and YH, the paths are parallel to one another. Hence the Boolean transmission function can be written as

$$T = A \cap X \cap Y \cap H \cap [(B \cap S_1 \cap E) \cup (C \cap S_2 \cap D) \cup$$
$$(B \cap S_1 \cap F \cap Z \cap G \cap S_2 \cap D) \cup (C \cap S_2 \cap G \cap Z \cap F \cap S_1 \cap E)]$$

The probability for reliable operation, i.e. reliability can be written as

$$P(T) = R = P(A \cap X \cap Y \cap H)\, P[(B \cap S_1 \cap E) \cup (C \cap S_2 \cap D) \cup (B \cap S_1 \cap F \cap Z \cap G \cap S_2 \cap D) \cup (C \cap S_2 \cap G \cap Z \cap F \cap S_1 \cap E)]$$

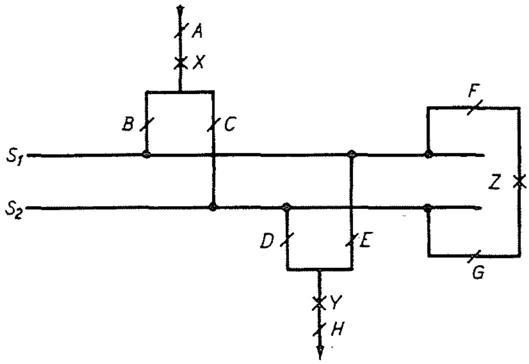

Fig. 3

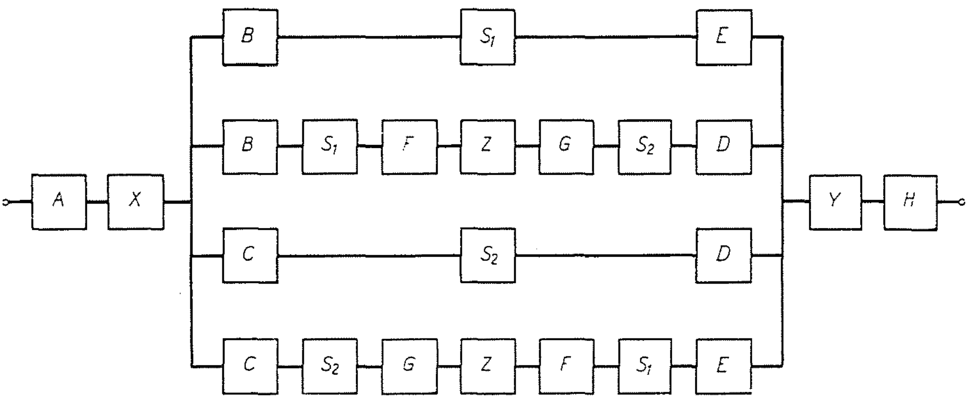

Fig. 4

Solving this equation further, and then applying the absorption law, we get,

$$R = R_S^4\, R_B\, R_C^4 (2 - R_S^2\, R_B + 2\, R_S^2\, R_B\, R_C\, Q_S^2)$$

Usually, the value of Q_S is very small and thus the term $2\, R_S^2 R_B R_C Q_S^2$ would be negligible. Then the above equation reduces to

$$R = R_S^4\, R_B\, R_C^2 (2 - R_S^2\, R_B) \tag{2}$$

2.3. *Double bus-bar double circuit-breaker scheme*

The connection diagram and the reliability block diagram are shown in Figs 5 and 6, respectively.

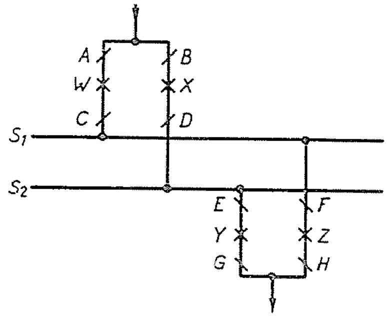

Fig. 5

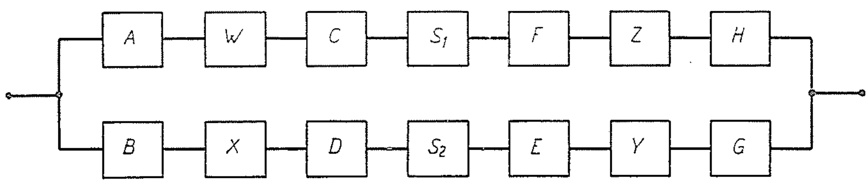

Fig. 6

There are two paths which are parallel to one another. These are:

Path I $A \cap W \cap C \cap F \cap Z \cap H \cap S_1$
Path II $B \cap X \cap D \cap E \cap Y \cap G \cap S_2$

The Boolean transmission function can be written as:

$$T = (A \cap W \cap C \cap F \cap Z \cap H \cap S_1) \cup (B \cap X \cap D \cap E \cap Y \cap G \cap S_2)$$

The reliability equation can be written as:

$$P(T) = R = P[(A \cap W \cap C \cap F \cap Z \cap H \cap S_1) \cup (B \cap X \cap D \cap E \cap Y \cap G \cap S_2)]$$

Solving this equation further, we get

$$R = R_S^4 R_C^2 R_B (2 - R_S^4 R_C^2 R_B) \quad (3)$$

2.4. *Double bus-bar single breaker scheme with by-pass isolator (High double bus-bar type)*

In this scheme, the by-pass isolator is provided in the incoming circuit. The connection diagram is shown in Fig. 7. The parallel paths are:

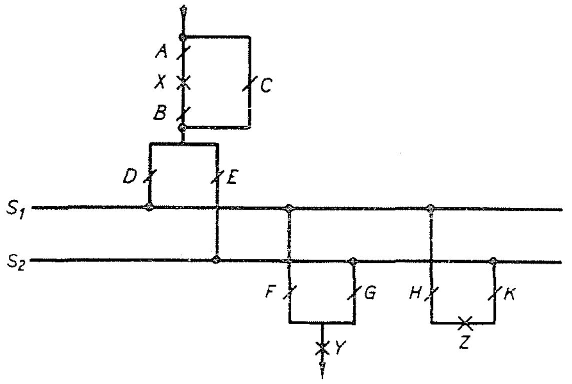

Fig. 7

Path I	$A \cap X \cap B \cap D \cap S_1 \cap F \cap Y$
Path II	$A \cap X \cap B \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G \cap Y$
Path III	$A \cap X \cap B \cap E \cap S_2 \cap G \cap Y$
Path IV	$A \cap X \cap B \cap E \cap S_2 \cap K \cap Z \cap H \cap S_1 \cap F \cap Y$
Path V	$C \cap D \cap S_1 \cap F \cap Y$
Path VI	$C \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G \cap Y$
Path VII	$C \cap E \cap G \cap S_2 \cap Y$
Path VIII	$C \cap E \cap S_2 \cap K \cap Z \cap H \cap S_1 \cap F \cap Y$

Out of these paths, we notice that paths V and VII have no circuit-breaker in the incoming side and hence these paths cannot be considered for practical use. The remaining six paths can be considered for the reliability calculations. The reliability block diagram is shown in Fig. 8. The Boolean transmission function can be written as:

$$T = [(A \cap X \cap B \cap D \cap S_1 \cap F) \cup (A \cap X \cap B \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G) \cup (A \cap X \cap B \cap E \cap S_2 \cap G) \cup (A \cap X \cap B \cap E\ S_2 \cap K \cap Z \cap H \cap S_1 \cap F) \cup (C \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G) \cup (C \cap E \cap S_2 \cap K \cap Z \cap H \cap S_1 \cap F)] \cap Y$$

and $R = P(T)$

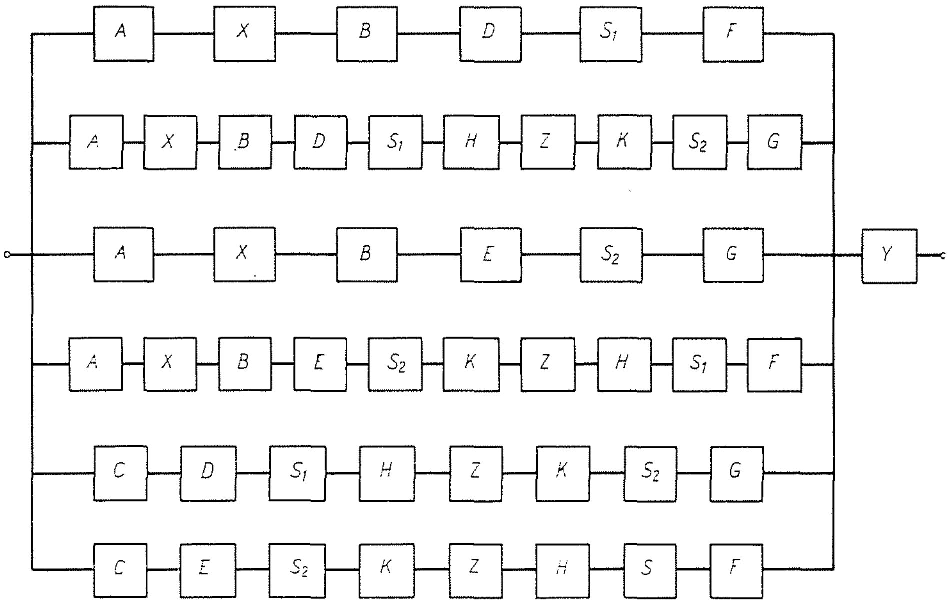

Fig. 8

Solving it further, we get

$$R = R_S^4 R_B R_C^2 (2 + 2 R_S R_B - R_S^2 R_B + 2 R_S^2 R_B R_C - R_S^3 R_B - \\ - 6 R_S^3 R_B R_C + 2 R_S^4 R_B R_C + R_S^5 R_B R_C) \tag{4}$$

2.5. *Double bus-bar single breaker scheme with by-pass isolator (Low double bus-bar type)*

In this scheme, the position of by-pass isolator is different from that in the scheme of 2.4 above. The connection diagram is shown in Fig. 9. The parallel paths are:

Path I $A \cap X \cap B \cap D \cap S_1 \cap F \cap Y$
Path II $A \cap X \cap B \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G \cap Y$
Path III $A \cap X \cap B \cap E \cap S_2 \cap G \cap Y$
Path IV $A \cap X \cap B \cap E \cap S_2 \cap K \cap Z \cap H \cap S_1 \cap F \cap Y$
Path V $C \cap S_1 \cap F \cap Y$
Path VI $C \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G \cap Y$

Out of these paths, we notice that path V has no circuit-breaker in the incoming side. Hence, we cannot consider this path for reliability calculations. The reliability block diagram is shown in Fig. 10. The Boolean transmission function for the paths can be written as

$$T = [(A \cap X \cap B \cap D \cap S_1 \cap F) \cup (A \cap X \cap B \cap D \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G) \cup (A \cap X \cap B \cap E \cap S_2 \cap G) \cup (A \cap X \cap B \cap E \cap S_2 \cap K \cap Z \cap H \cap S_1 \cap F) \cup (C \cap S_1 \cap H \cap Z \cap K \cap S_2 \cap G)] \cap Y$$

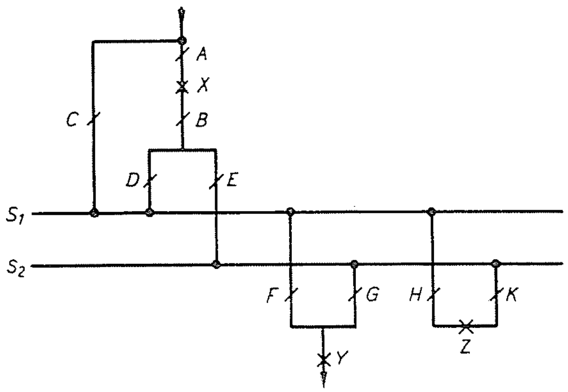

Fig. 9

The probability for reliable operation is

$$R = P(T)$$

Simplifying the above equation, it can be proved that

$$R = R_S^4 R_B R_C^2 (2 + R_B - R_S^2 R_B + 2 R_S^2 R_B R_C - - 5 R_S^3 R_B R_C + 2 R_S^4 R_B R_C) \tag{5}$$

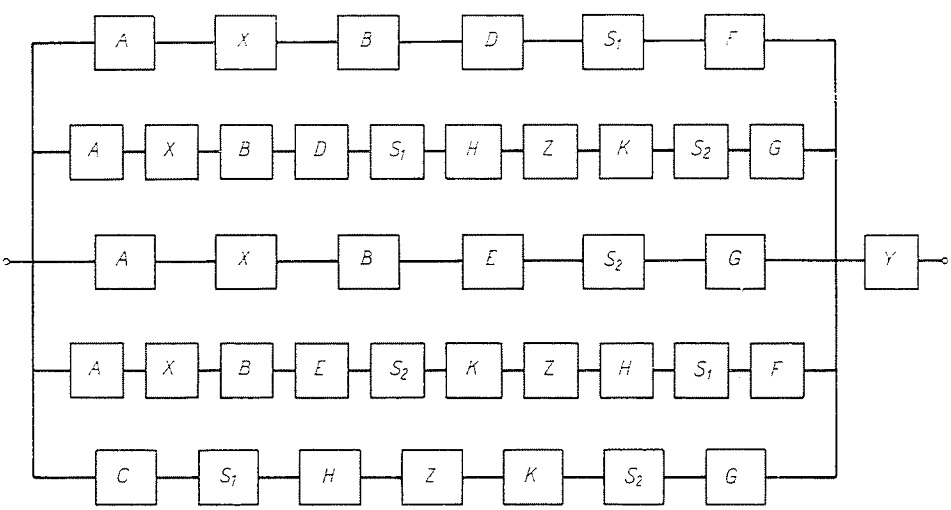

Fig. 10

3. Comparison for 120 kV network voltage

Before substituting the reliability values in the formulae proved above, it must be stated that a discrete period must be chosen so that outages, due to equipment breakdowns, lasting for a time more than this discrete period would be accounted towards the unreliability of that particular apparatus. By giving careful thought, this period has been chosen as 3 minutes. This is the approximate time required for the changeover of branches with the help of the bus-coupler. The approximate values of the unreliabilities of the isolating switches and bus-bars in Hungary are:

$$Q_S = 5 \cdot 10^{-6}$$

and

$$Q_S = 10^{-6}$$

Substituting these values in the formulae derived in the previous chapter, we get the simplified formulae:

Scheme No.	Reliability formulae in term of R_C
2.1	$0.999979R_C^2$
2.2	$0.99999R_C^2$
2.3	$1.999958R_C^2 - 0.999958R_C^4$
2.4	$1.999973R_C^2 - 0.999973R_C^3$
2.5	$1.999968R_C^2 - 0.999968R_C^3$

Now the comparison can be divided into two parts:

1. to test the sensitivity of the schemes for the sensitivity of the circuit-breaker reliability,

2. to assume the normal reliability of the circuit-breaker and the normal costs and compare the schemes.

3.1. The unreliability of the circuit-breaker normally ranges from 20×10^{-6} to 200×10^{-6}. Substituting these values in the formulae derived, we get the following results:

Unrel. of C. B.	Scheme			Number	
	2.1	2.2	2.3	2.4	2.5
20	61	50	0.003	20	20
40	101	90	0.007	40	40
60	141	130	0.01	60	60
100	221	210	0.02	100	100
150	321	310	0.03	150	150
200	421	410	0.035	200	200

All values stated above are to be multiplied by 10^{-6}.

Fig. 11 shows the graph plotted between the unreliability of the circuit-breaker and the unreliability of the schemes. A few important conclusions which can be drawn from the graph are:

(i) The relation between Q and Q_C is practically linear.

(ii) The reliability of the double bus-bar double breaker scheme is *very* high. It also indicates that Q_C of the breaker may be high, but by using such breakers in this scheme, high reliability for the scheme can be obtained. Approximately, Q is of the order of 1/5000 of the value of Q_C.

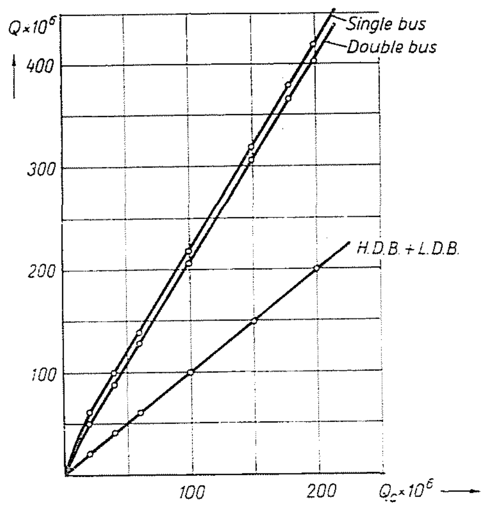

Fig. 11

(iii) There is not much difference between the reliabilities of single and double bus-bar schemes.

(iv) The two by-pass isolator schemes offer the same reliabilities and this value is quite high compared to that of one without by-pass isolator.

3.2. The comparison based on the costs of the schemes cannot be very precise because of the fact that we have taken a part of the sub-station for comparison. However, it would certainly give us the idea of cost *vs.* reliability for that part and thus the superiority of one scheme over the other. As the bus-coupler can be used for two or more lines, half the cost of the bus-coupler has been included in the estimate. The costs are:

Scheme No.	Cost in million Ft.
2.1	3.80
2.2	5.025
2.3	6.6
2.4	5.275
2.5	5.375

Fig. 12 shows the scheme No. *vs.* the cost and unreliability. Here, the unreliability of the scheme has been calculated for the circuit-breaker unreliability of 40×10^{-6}, which has been found to be the normal circuit-breaker unreliability for 120 kV in Hungary. It can be tabulated as:

Scheme No.	Reliability	Unreliability	Cost: in million Ft.
2.1	0.999899	101×10^{-6}	3.80
2.2	0.99991	90×10^{-6}	5.025
2.3	0.999999993	0.007×10^{-6}	6.6
2.4	0.99996	40×10^{-6}	5.275
2.5	0.99996	40×10^{-6}	5.375

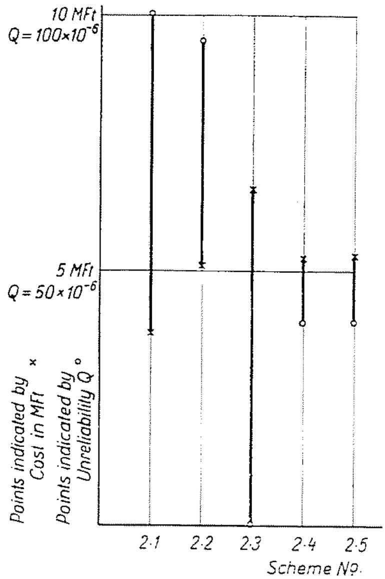

Fig. 12

The following conclusionscan be drawn:

(i) Double bus-bar double circuit-breaker scheme offers *very* high reliability, but the cost is also *very* high. Thus, if reliability is the only criterion for selection, then this scheme is a must.

(ii) The two schemes of by-pass isolator offer the same reliability. Thus, the old consideration of selecting one amongst these two, that of availability of land, can still hold good. Further, these two schemes offer much higher reliability than that without by-pass isolator. These schemes offer better maintenance facilities and should always be preferred.

(iii) From the operational reliability point of view, the single bus-bar and double bus-bar schemes do not much differ. Further, there is not much difference in the maintenance facilities available. It is thus gratifying to know that single bus-bar scheme is preferred in Hungary, to the double bus-bar scheme.

4. Thus, in conclusion it must be stated that reliability of the circuit-breaker is extremely important for the reliability of the sub-station as a whole. It is always worth to buy a good circuit-breaker with high reliability and use a simple scheme for the sub-station rather than to buy a bad one and use a complicated scheme, involving additional possibility of supply failure due to "human-initiated failures". For example:

Reliability of scheme No. 1 with cost of 3.80 MFt. and $Q_C =$ $= 20 \times 10^{-6}$	=	Reliability of scheme No. 4 with cost of 5.275 MFt. and $Q_C =$ $= 60 \times 10^{-6}$

The difference between the costs of circuit-breakers having $Q_C = 20 \times 10^{-6}$ and $Q_C = 60 \times 10^{-6}$ would certainly not be to the extent of $5.275 - 3.80 =$ $= 1.475$ MFt. Similar comparison can be done for the other schemes too.

Summary

This paper deals with the reliability calculations pertaining to the electric sub-stations. As it is very difficult to consider a whole sub-station for general comparison purposes, only one set of incoming and outgoing line has been considered. Detailed calculations have been performed for such ways and reliability formulae for different types of sub-stations have been derived. Cost factor has also been taken into consideration and it has been proved that a good quality circuit-breaker with high reliability would permit us to use a simpler scheme at less cost and at the same time giving high reliability for the scheme as a whole. Thus considerable economy can be achieved by using a costly but highly reliable circuit-breaker. Boolean algebra has been used for the calculations.

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S. S. Pingle, Assistant Professor of Electrical Engineering, College of Engineering, Amravati, Maharashtra State, India