International Journal of COLLEGE SCIENCE IN INDIA

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Vol. 3 : 2 July 2009

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Abstract

Reliability is always a concern for Power Systems. Reliability is a compromise between security and dependability. Security is the ability to properly restrain from tripping when not called for. Dependability is the ability to trip when required. While security is not improved by increased redundancy, dependability is. Clearly, the impact on the power system when a power transmission circuit and protective devices are not functioning when required is much less severe when there is a redundant transmission circuit & protective devices that takes over the job. If the two redundant transmission circuit and protective devices are of equal performance, there should be no detrimental effect at all on power system operations, and a non-functioning device would just need to be repaired or replaced.

The Power industry applies a "no single point of failure" criteria for Power system networks. Reliability is commonly achieved by configuring the Power Transmission lines various circuits and protective devices placement schemes. For Power system networks and component devices, the preferred method of meeting reliability requirements has been to use physically separate, redundant transmission circuits and protective devices.

Hence, this paper is examining redundancy requirements for Power system transmission circuits and protective devices configuration in System and presents a new approach for evaluating the reliability of system.

Keywords: **Circuit breaker, Fault Tree, Power system, Probability, Reliability, redundant devices, wind farm.**

1.0 Introduction

1.1 Definition of Power System Reliability

The function of an electric power system is to satisfy the system load requirement with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability.

The concept of power system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements.

There is a reasonable subdivision of the concern designated as ‘system reliability’, which is shown in Figure 1.

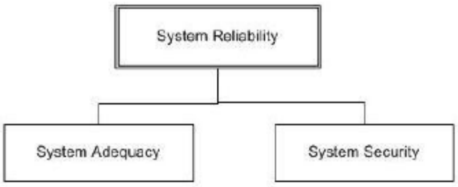


Figure 1 System reliability

1.2 Subdivision of System Reliability

Figure 1 represents two basic aspects of a power system: system adequacy and security. Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Security relates to the ability of the system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to perturbations. Most of the probabilistic techniques presently available for power-system reliability evaluation are in the domain of adequacy assessment. The techniques presented in this paper are also in this domain.

1.3 Reliability

Reliability is a product of two factors; dependability and security. For transmission line circuits and protective devices, dependability is defined as the ability to isolate for a fault within its protective zone while security is the ability to refrain from isolating when there is no fault in the power system zone.

While not practical to use, it could be of interest to illustrate the concepts by looking at the two extremes; 100% dependability and 100% security. 100% dependability would be achieved by a power system that is in constantly isolated state, hence there is no possibility that there would be a fault that would not be detected. 100% security would be achieved by disabling the power system entirely so that it could not isolate. From this it can be seen that while high dependability and high security are desirable, they will both have to be less than 100%. Generally, an increase in dependability will decrease security and vice versa. However, measures to increase dependability may not penalize security to an equal degree and the aim of a protection system design is to find the optimum combination of the two factors in order to provide adequate reliability of the power system.

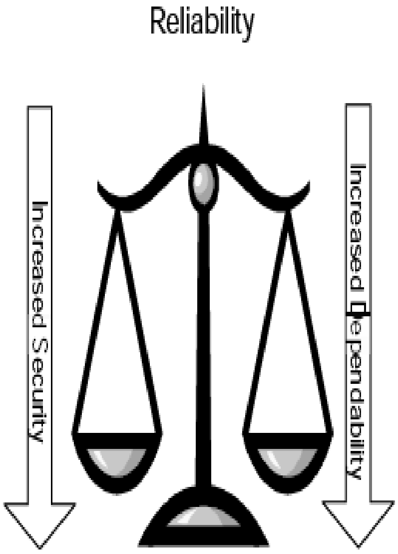


Figure 2 Reliability, dependability and security

1.4 Dependability

For the power system, dependability is easy to define and to measure. Any zone fault that is not isolated by the protective device is considered lack of dependability. The reciprocal of dependability could be called ‘failure to isolate’.

For example, if a system has a dependability of 99%, the failure to isolate would be 1% which means that of 1 out of 100 faults in the power system zone would not be tripped by the scheme.

1.5 Security

Security is the ability not to trip when not called for. To put a number on security is not as easy as for dependability. A simple method would be to compare the number of false trips for faults external to the protected zone by device component as compared to the total number of external faults. However, this does not consider other phenomena; false trips due to relay failure, trips on stable power swings, inrush currents or other phenomena that are not necessarily classified as power system faults. Even an ‘external fault’ is not readily defined as it depends on what extent of the adjacent power system is included in the fault count.

1.6 Redundancy

Redundancy is defined as ‘the existence of more that one means for performing a given function’. It is obvious that protective device and transmission system dependability can be increased by added redundancy as if one of the systems does not trip for an in-zone fault. If a fault occurs and is isolated from a backup (or redundant) protective device and transmission system, the fact that the primary protective device system did not operate does not constitute a mal -operation. The reason for this is obvious; as long as the fault is correctly tripped, there is no reason to investigate whether all parts in the protective device system actually operated as intended.

In the following discussions, ‘redundant’ refers to completely independent transmission line systems or components. The failure rate for each system or component is independent from the redundant system’s failure rate. A failure in one device does not influence the other and the failures are not triggered by a common cause.

For our redundancy considerations, the requirements given for a Direct Trip
Protective System are used:

a) □ 99.9999% security or expressed as probability of a false trip (reciprocal of security), 10^{-6} or 1/1,000,000

b)99.99% dependability or expressed probability of a missed trip (reciprocal of dependability),10^{-4} or 1/10,000

1.7 Security in a redundant system

If we add a redundant system, and the systems are equal and independent, the probability of a false trip will be the sum of the probability for each redundant system to give a false trip:

a)□ Probability of a false trip for a redundant system
= 2/1,000,000 or expressed as security: 99.9998%

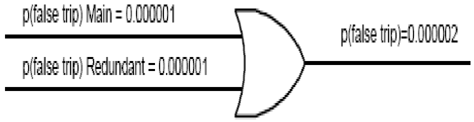


Figure 3 Probability for false trip in a redundant system

Security is reduced from 99.9999% for a single system to 99.9998% for a redundant system, which is not a significant change.

1.8 Dependability in a redundant system

The probability of a missed trip however, will be greatly reduced, resulting in much improved dependability. If the systems are equal and independent, both of them need to fail at the same time for a missed trip to occur. Therefore the resulting probability of a missed trip is the product of the individual probability:

Probability of a missed trip for a redundant system

= 1/10,000 x 1/10,000
=1/100,000,000 or expressed as dependability: 99.999999%

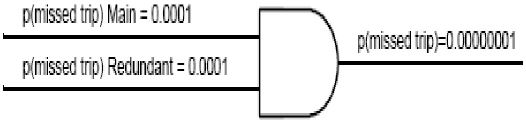


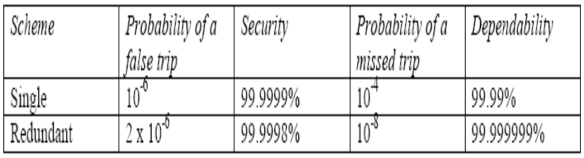
Figure 4 Probability for a missed trip in a redundant system

Consequently, dependability has increased from 99.99% to 99.999999%.

1.9 Influence of redundancy on security and dependability

The table below summarizes the influence of redundancy on security and dependability for the example used with individual unit probability of a false trip of 10^{-6} and probability of a missed trip of 10^{-4}.

Table 1



Scheme	*Probability of a false trip*	*Security*	*Probability of a missed trip*	*Dependability*
Single	10^{-6}	99.9999%	10^{-4}	99.99%
Redundant	2×10^{-6}	99.9998%	10^{-8}	99.999999%

The above example hopefully explains why redundancy is important for protective device system reliability. By adding a second redundant system the probability of a false trip increased by a factor of 2, but the probability of a missed trip decreased by a factor of 10,000.

1.10 Reliability of a Circuit breaker system

The circuit breaker is just one component that needs to function correctly for the transmission system to operate as intended. Other components are: relay, measuring transformers, battery system, control circuits, protection devices and any communications channels. While it is of interest to examine the performance of all these components, this paper will discuss only circuit breaker system reliability.

Mal operations caused by circuit breaker devices can have many causes:

a) Equipment electrical hardware & mechanical parts failure
b) Relay measuring limitations
c) Incorrect settings or improper application
d) Control wiring problems

Redundancy can improve each of these factors, but in different ways:

1.10.1 Equipment hardware & mechanical parts failure

The use of redundant circuit breaker systems will greatly improve dependability for equipment failures. Security could be adversely affected by added redundancy, but the likelihood is small. There is a risk that a electrical hardware failure could cause a false trip before being taken out-of-service by the self-supervision, but this is not a very common occurrence.

For hardware failures, the choice of identical or different redundant systems would make little difference. Exceptions would be if there is a common mode failure or a design flaw that would be affected by common external factors.

The mechanical parts failure or malfunction of main & auxiliary contacts of the circuit breaker , interlocking & closing or opening mechanism cause a false operation.

1.10.2 Relay measuring limitations

Redundancy will not improve dependability for relay measuring limitations unless they are of different design, or at least use different settings, eliminating the possibility of identical limitations in both devices. This fact has influenced the practice of applying different measuring principles, and designs, for the Main 1 and Main 2 circuit breaker schemes. Recognizing that it might be difficult to design a scheme that would cover all conceivable system fault conditions, it has been common to apply two schemes to complement each other. As correct fault clearing requires just one main protection to operate properly, this practice has proved to be very effective.

1.10.3 Incorrect settings or improper application

Incorrect settings and improper application will affect both dependability and security. A redundant device or function will improve dependability but it will also decrease security. The large number of additional functions available in the multi-function devices may have a greater negative impact on security than the relatively marginal improvement in dependability. Many of these functions are for back-up and are rarely called on to operate, but an incorrect setting may cause a false trip.

1.10.4 Control wiring problems

Control wiring problems can be divided into different categories; relay, battery, measuring transformer, and breaker trip and communication circuits. Some of these can be made redundant while others may be too costly to consider. A second communication channel will greatly improve protection scheme dependability but may be difficult to realize. Adding redundancy in the protection equipment itself can improve dependability for control wiring.

Examples are:

a) Redundant power supplies fed from different battery systems

b) Redundant trip outputs operating on different trip coils

c)□ Redundant digital input boards

d)□ Redundant communications interfaces

e) Main 1 and Main 2 protections connected to different measuring transformers or different secondary windings

2.0 Reliability Analysis of circuit breaker in Double circuit Transmission lines:

The Circuit Breakers CB1& CB3 are connected in a series sub circuit & CB2 & CB4 are connected in series in another sub circuit & both are connected in parallel to form the double circuit transmission lines as shown in figure5.

Each circuit breaker system can be in a functioning state or in a non-functioning state. Hence, every circuit breaker can be assigned a Boolean variable which can assume a value 1 if it is functioning & a value 0 if it is not functioning. Similarly, when some of these circuit breakers are connected in parallel combinations, the output event can also be represented by a Boolean variable capable of assuming either a value 1 or 0.

2.1 Construction of Fault Tree

The starting point is the occurrence of a single, well defined undesirable event of failure or the non-functioning (F) of the system. This undesirable event occurs as a result of the combinations of undesirable events at the levels of circuit breakers & groups of circuit breakers. If a Boolean variable is associated with each basic event, then the undesirable final event for Boolean variable can be obtained.

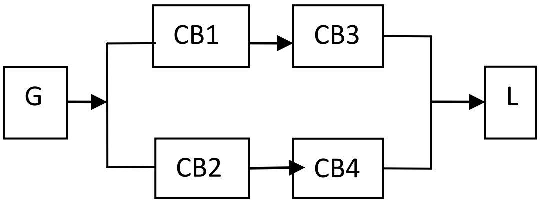


Figure 5 Double circuit Transmission lines Configuration
G = Generator, L = Load, C.B. =circuit Breaker

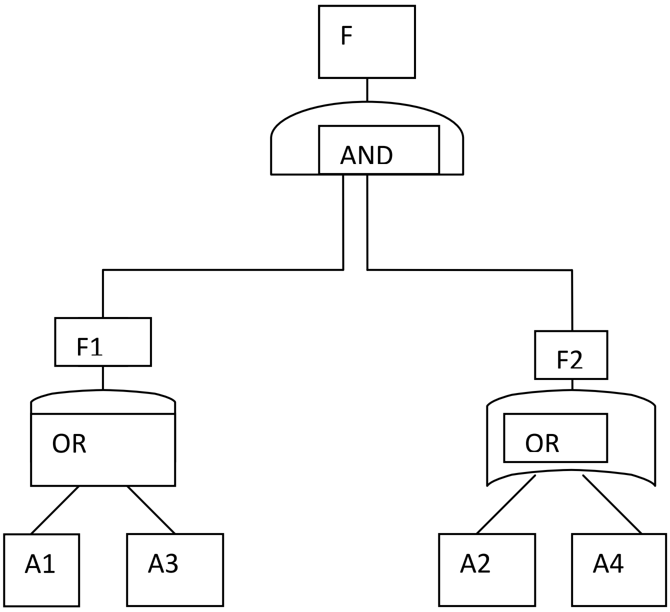


Figure 6
Fault Tree Diagram

In the Fault Tree diagram of Figure 6, the Boolean variables associated are

A_1: Failure of Circuit Breaker CB_1,
A_2: Failure of Circuit Breaker CB_2,
A_3: Failure of Circuit Breaker CB_3,
A_4: Failure of Circuit Breaker CB_4,

2.2 Reliability Analysis

The failure of CB_1 or CB_3 causes the failure of sub-system 1.

In the language of Boolean algebra, the occurrence of A_1 or A_3 causes event F_1 to occur, thus
$F_1 = (A_1+A_3)$ ……………………… (1)

Similarly, the occurrence of A_2 OR A_4 causes event F_2 to occur, thus
$F_2 = (A_2+A_4)$ ………………………… (2)

The occurrence of the final event F takes place when events F_1 AND F_2 occur, i.e.
$F = F_1.F_2$ ……………………………… (3)

Substituting the expressions corresponding to F_1 and F_2, we get
$F = (A_1+A_3).(A_2+A_4)$
$= A_1A_2+A_1A_4+A_2A_3+A_3A_4$ ………… (4)

The system obviously fails when
Circuit breaker CB_1 and CB_2 fail (corresponding to A_1A_2)
or
Circuit breaker CB_1 and CB_4 fail (corresponding to A_1A_4)
or
Circuit breaker CB_2 and CB_3 fail (corresponding to A_2A_3)
or
Circuit breaker CB_3 and CB_4 fail (corresponding to A_3A_4).

The plus sign in the Boolean expression stands for the OR operation.

The terms appearing in Eq. (4) are nothing but the minimal cut sets. The Boolean variables $A_1, A_2, \ldots$are binary variables capable of assuming a value 0 or 1, the way these variables are used in a fault tree diagram is such that each of these variables has assumed a value 0, indicating failure.

Thus, in Eq. (1), (2) and (3)

$F_1 = A_1+A_3 = 0+0=0$,
$F_2 = A_2+A_4 = 0+0=0$,
$F = F_1.F_2 = 0.0=0$.

Equation (4) also substantiates the fact that according to Boolean algebra F=0 only when $A_1A_2=0$, $A_1A_4=0$, $A_2A_3=0$, $A_3A_4=0$.

2.3 Probability Calculations

Equation (4) depicts that event F (i.e. failure of the system) occurs when A_1A_2 or A_1A_4 or A_2A_3 or A_3A_4 occurs.

Therefore, the probability of failure of the system is F(S)

$=P\ (A_1A_2+A_1A_4+A_2A_3+A_3A_4)$
$=P\ [A_1\ (A_2+A_4)\ +A_3\ (A_2+A_4)]$
$=P\ [(A_1+A_3)\ (A_2+A_4)]$
$=P\ (A_1+A_3)\ P\ (A_2+A_4)$
$=[P(A_1)+P(A_3)-P(A_1A_3)][P(A_2)+P(A_4)-P(A_2A_4)]$.

The circuit breakers are independent and P (Ai) is the probability of failure of circuit breaker Ci.

Hence, if Ri is the reliability of the circuit breaker, then
P (Ai) = 1-Ri

Where (i =1, 2, 3, 4),

Substituting these, F(S)

$= [(1-Ri) + (1-R_3) -(1-R_1)(1-R_3)][(1-R_2)+ (1-R_4)-(1-R_2)(1-R_4)]$
$= (1-R_1R_3)\ (1-R_2R_4)$
$= 1-R_1R_3-R_2R_4+R_1R_2R_3R_4$

Therefore, the reliability of the system is
R(S)

$= 1-F(S)$
$= R_1R_3+R_2R_4-R_1R_2R_3R_4$.

The successful operation of the system depends on the successful functioning of path CB_1 CB_3 or CB_2CB_4.

Hence; the probability of successful operation of the system circuit [a] i.e. the path is CB_1 CB_3 or CB_2CB_4 in figure5.

This is expressed by
$P_a(S)=P(CB_1)*P(CB_3)+P(CB_2)*P(CB_4)-P(CB_1)*P(CB_2)*P(CB_3)*P(CB_4)$… (5)

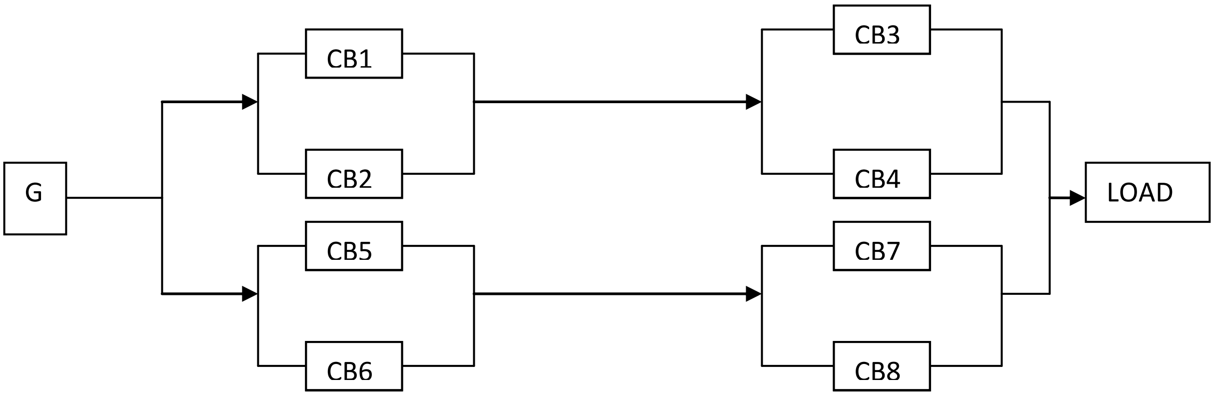


Figure 7:Sending end Sub-Station Transmission lines Receiving end Sub-Station Proposed parallel Circuit Breaker Double circuit Transmission lines Configuration

G= Generator, CB= Circuit Breaker

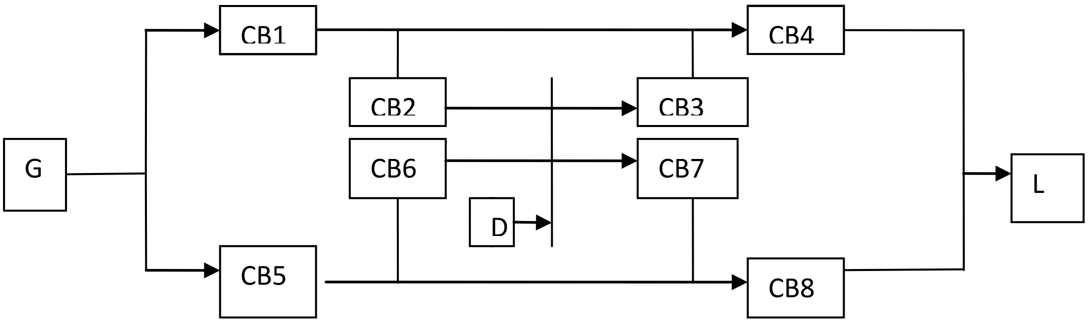


Figure 8

Sending end Sub-Station has CB1 & CB5,Intermediate Sub-station circuit breakers consists of CB2, CB3, CB6 & CB7 connected with Bus of Renewable Generation and Receiving station substation CB4 & CB8 having Double circuit long Transmission lines as a Bridge configuration

G= Generator, CB= Circuit Breaker 1, 2, 3, 4, 5, 6, 7, 8, D= Distributed Generation (Provision),
L=Load

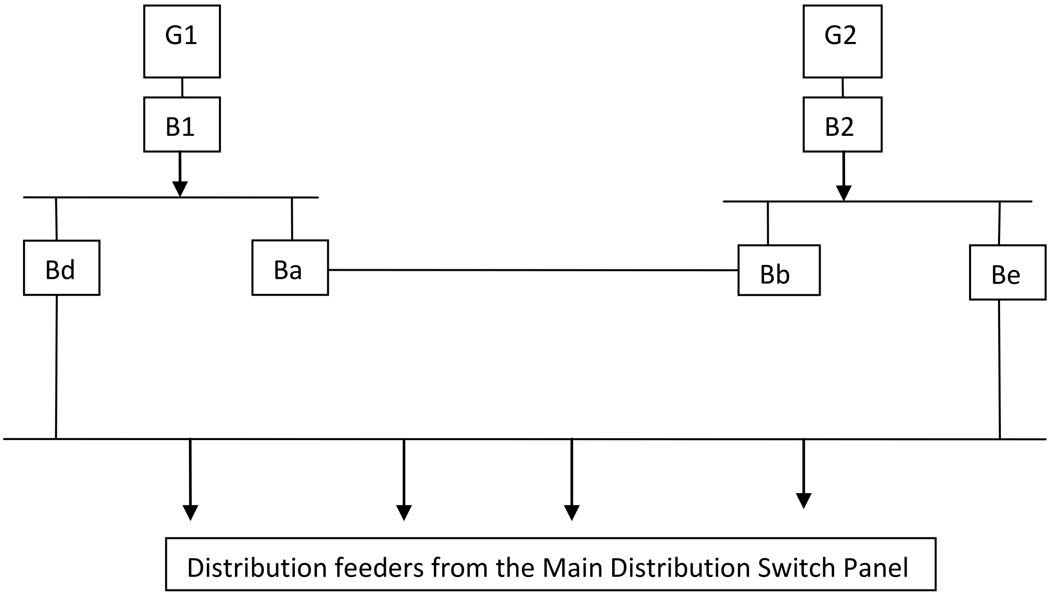


Figure 9:Wind farm

G1=Wind Generator,B1,B2=Generator Breakers, Ba, Bb, Bd, Be=Circuit Breakers
Similarly, to determine the reliability in the case of system circuit no.1 [b] in figure7
i.e. the path is CB_1 or CB_2 and CB_3 or CB_4.

This is expressed by

$P_b(S)$

$$= P[(CB_1 \text{ OR } CB_2) \text{ AND } (CB_3 \text{ OR } CB_4)]$$
$$= P[(CB_1 \text{ OR } CB_2) * (CB_3 \text{ OR } CB_4)]$$
$$=[P(CB_1)+P(CB_2)-P(CB_1)*P(CB_2)]*[P(CB_3)+P(CB_4)-P(CB_3)*P(CB_4)] \ldots\ldots\ldots\ldots \quad (6)$$

To compare these reliabilities, let the elements be identical, each of reliability p, from equation (5)

$P_a(S)$
$$=2p^2-p^4$$
$$=p^2 (2-p^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Similarly from equation (6)
$P_b(S)$
$$=(2p-p^2)(2p-p^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$P_b(S) / P_a(S)$
$$= 1+2(1-P)^2/2-P^2 \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The ratio quantity which is vividly evident from equation ($_9$) is greater than one and thus the proposed system has greater reliability.

Similarly, the reliability in the case of system
circuit no.1 [c] in figure 7 i.e. the path is CB_5 or CB_6 and CB_7 or CB_8.
This is expressed by

$P_c(S)$
$= P [(CB_5 \text{ OR } CB_6) \text{ AND } (CB_7 \text{ OR } CB_8)]$
$= P [(CB_5 \text{ OR } CB_6) * (CB_7 \text{ OR } CB_8)]$
$=[P(CB_5)+P(CB_6)-P(CB_5)*P(CB_6)]*[P(CB_7)+P(CB_8)-P(CB_7)*P(CB_8)]$………………(10)

Similarly from equation (10)
$P_{c\,(}S)$
$=(2p-p^2)(2p-p^2)$…………………………(11)

$Pc(S) / P_a(S)$
$= 1+2(1-P)^2/2-P^2$ …………………..(12)

The ratio quantity which is vividly evident from equation (12) is greater than one.

Thus the proposed system has greater reliability due to addition of circuit b and c.

It is shown that the component redundancy is superior to sub system redundancy. Therefore, the developed concept in this paper will help the designers for system either to improve reliability of existing networks or to satisfy the requirement of uninterrupted power supplies needed for essential services from radial distribution feeders instead of adopting ring distribution system, since the transmission lines are spread all over the country to give supply to remotest village in radial configuration mode only.

Figure 8 shows the double circuit long Transmission lines with Intermediate sub-station consisting of circuit breakers CB_2, CB_3, CB_6, CB_7 with Renewable Distributed Generation Interconnection in the middle,
a classical example known as the bridge system, which can not be reduced to a simple mixture of series & parallel configurations.

This problem is proposed to be solved by using the concept of successful paths.

Let Generator terminal is denoted as G and load terminal is represented as L. Generally, there may be more than one input terminals depending on the number of redundancies provided in the power system.

The successful functioning of the system is the flow from G to L. This flow from G to L can take place if there is at least one successful path from G to L.

The successful paths in Figure8 are

CB_1-CB_4, CB_1-CB_2-CB_3-CB_4, CB_5-CB_8,
CB_5-CB_6-CB_7-CB_8, CB_1-CB_2-CB_7-CB_8,
CB_5-CB_6-CB_3-CB_4.

Consider paths CB_1-CB_4 and CB_1-CB_2-CB_3-CB_4.For any one of these two paths to be successful, $CB_1$and CB_4 have to work. CB_2 and CB_3, whether or not it works is inconsequential so far as these two paths are concerned. Similarly, when considering the paths CB_5-CB_8 and CB_5-CB_6-CB_7-CB_8, CB_6 and CB_7 are of no consequence. Hence the successful paths for the bridge system are

CB_1-CB_4, CB_5-CB_8, CB_1-CB_2-CB_7-CB_8,CB_5-CB_6-CB_3-CB_4.
Let R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 be the respective reliabilities of the eight Circuit Breakers.

The system reliability is given by
R (S)
= P [($CB_1$and CB_4)or (CB_5 and CB_8)or ($CB_1$and $CB_2$and $CB_7$and CB_8) or ($CB_5$and$CB_6$and $CB_3$and CB_4)] ………(13)

The novel concept developed for formation of equations in this paper earlier can be expressed now on the similar way to show that the reliability of radial transmission system with the proposed circuit breaker configuration has further enhanced the reliability of the power system. Further, the addition of Distributed Generation at the intermediate substation stage will give uninterrupted power supply to the consumers.

3.0 Distributed Generation Wind Farm

A simple case is illustrated of a wind farm Generation in figure 9 having two wind mills G1 and G2, each connected to its respective main Bus bars through Circuit Breakers B1and B2 respectively. The main distribution switch panel receives supply from the main bus bar panel through cables C1, C2 and respective breakers Bd and Be. The two main bus bars are interconnected through a long cable C3 and the circuit breakers Ba and Bb.

Let us assume that basic components subjected to failure are generators G1 and G2 (A1and A2), main bus bars 1and 2(A3 and A4), interconnecting cable c3 and circuit breakers Ba and Bb all treated as one unit (A5),circuit breakers Bd and Be (A6,A7) and Distribution feeder switch panel(A8).The assumption is that the generators, the main bus bars panel, the breakers and the distribution panel etc. are taken as the super components and are dealt with as a single units.

3.1Reliability calculation by Boolean Algebra

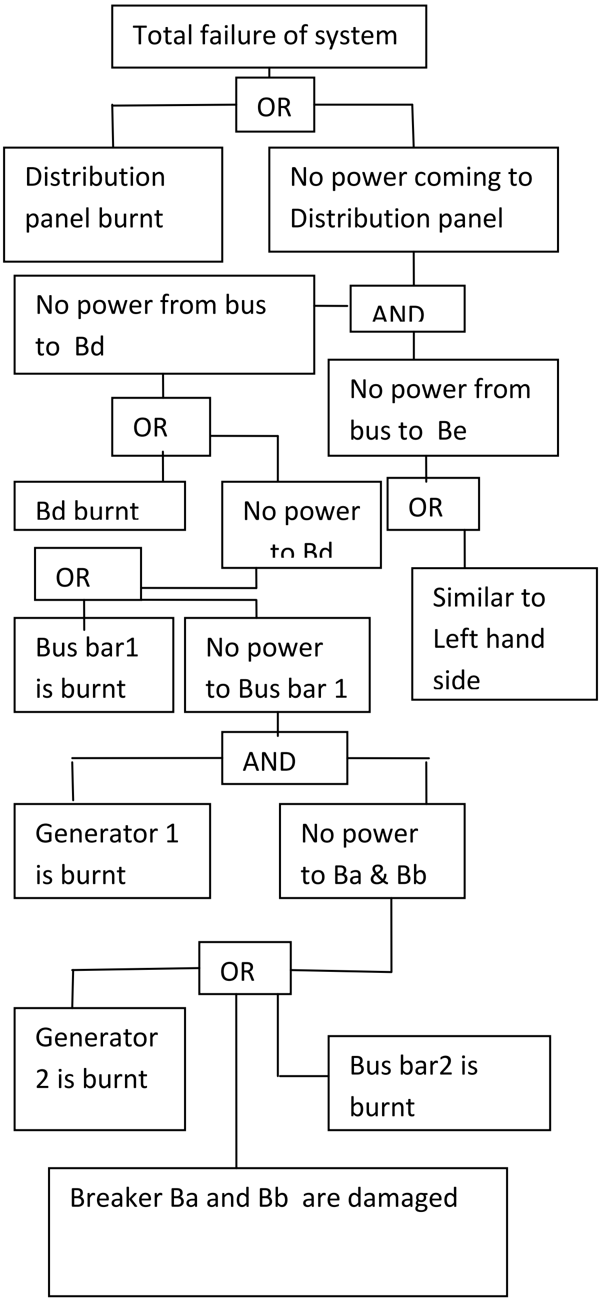


Figure10:Boolean Logic Diagram

The logic is represented from bottom upwards in figure10 and using + sign to indicate the OR operation and dot (.) to denote the AND operation the equations can be expressed as follows:

No power coming through breakers Ba and Bb

$F_1=A_2+A_5+A_4$;

No power coming to bus bar1

$F_2=A_1.F_1=A_1.(A_2+A_5+A_4)$;

No power to breaker Bd

$F_3=A_3+F_2=A_3+[A_1.(A_2+A_5+A_4)$;

No power from the breaker Bd,

$F_4=A_6+F_3=A_6+A_3+[A_1.(A_2+A_5+A_4)]$;

Similarly, from the right half of the fault tree diagram, for

No power from the breaker Be

$F_8=A_7+A_4+[A_2.(A_1+A_5+A_3)]$;

No power coming to Distribution switch panel,

$F_9=F_4$ and F_8,i.e.;

$F_9=\{A_6+A_3+[A_1.(A_2+A_5+A_4)]\}.\{A_7+A_4+$

$[A_2.(A_1+A_5+A_3]\}$.

For the total failure of the system,

$F_{10}=A_8+F_9$.

Applying the usual absorption laws of Boolean algebra,

$F_{10}= A_8+\{A_6+A_3+[A_1.(A_2+A_5+A_4)]\}.\{A_7+A_4+$

$[A_2.(A_1+A_5+A_3)]\}$.

$F_{10}=A_8+(A_6+A_3+A_1A_2+A_1A_5+A_1A_4).(A_7+A_4+A_1A_2+A_2A_5+A_2A_3)$

$F_{10}=A_8+A_6A_7+A_4A_6+A_1A_2A_6+A_2A_5A_6+$

$A_2A_3A_6+A_3A_7+A_3A_4+A_1A_2A_3+A_2A_3A_5+A_2A_3+A_1A_2A_7+A_1A_2A_4+A_1A_2+A_1A_2A_5+A_1A_2A_3+$

$A_1A_5A_7+A_1A_4A_5+A_1A_2A_5+A_1A_2A_5+$

$A_1A_2A_3A_5+A_1A_4A_7+A_1A_4+A_1A_2A_4+ A_1A_2A_4A_5+A_1A_2A_3A_4$.

These terms are simplified further by noting that the units are not replicated i.e.$A_1A_2+A_1A_2A_3=A_1A_2$, which means that A_1 and A_2 OR $A_1$and $A_2$and A_5 is equivalent to just $A_1$and A_2. Thus,

$F_{10}=A_8+A_1A_2+A_1A_4+A_2A_3+A_3A_4+A_3A_7+A_4A_6+A_6A_7+A_1A_5A_7+A_2A_5A_6$.

This expression depicts the event combinations, i.e. cut sets that results in the total failure of the system.

The probability of failure is

$P(F_{10})=P(A_8+A_1A_2+A_1A_4+\ldots.+A_2A_3A_7)$.

This reliability is

$R=1-P\ (F_{10})$

$R=1-P(A_8+A_1A_2+A_1A_4+\ldots..+A_2A_5A_7)$.

$R=1-P\ (A_8)\ +P\ (A_1A_2)+..P\ (A_8)\ P\ (A_1A_2)..$

If $R_1,R_2,R_3,\ldots\ldots,R_8$ are the reliability factors, then

$R=1-(1-R_8) + (1-R_1)\ (1-R_2) +\ldots$

4.0 ‘r’ out of ‘n’ structure

A transmission line having n circuit breakers in which at least r circuit breakers are necessary to pass the required current, when n circuit breakers are independent and identical.

To obtain an expression for the probability of exactly r successes out of n identical independent trials in the complex circuit breaker configuration for passing the current to load, one way is to have r consecutive successes followed by n-r consecutive failures, since each success and failure is independent; the probability of the assumed sequence is expressed as

$P^r(1-p)^{n-r}$

Where,

p=the probability of one success.

The total probability of getting r successes out of n trials expressed in Bernoulli trial or binomial experiment is given below

$= (n/r)p^r(1-p)^{n-r}$.

To obtain an expression for the probability of at least r successes out of n identical independent trials is expressed as

The probability of exactly r successes

$= (n/r)p^r(1-p)^{n-r}$.

The probability of exactly r +1 success

$= (n/r)p^{r+1}(1-p)^{n-r+1}$.

Similarly, the probability of n successes

$=p^n$.

Therefore, the probability of getting at least r successes is the sum of the above stated expressions

$(n/r)p^r(1-p)^{n-r} +(n/r)p^{r+1}(1-p)^{n-r+1} +..+ p^n$ …. (14)

5.0 Optimization

This is assumed that every circuit breaker functions when it should with probability p ($0 < p < 1$) and does not function when there are no supply received or signal received with probability r ($0 < r < 1$).

Consider the system shown in figure8, consisting of four successful paths connected in parallel.

It is necessary that at least one of the circuit breakers paths functions when the supply or signal is given and at the same time none of them functions, when no supply or signal is available at the input terminals.

The probability that at least one of the parallel path functions when the supply or signal receives is equal to the probability that none of them fails, when the supply or signal is received and is equal to $[1-(1-p)^4]$.

The probability that none of them functions when no supply or signal is received is expressed as r^4.

Therefore, the system reliability is

$R = r^4[1-(1-p)^4]$.

If the system consists of m circuit breakers connected in parallel, then the system reliability is

$R_m = r^m [1-(1-p)^m]$ …………………..(15)

This is compared with the system, which does not malfunction, since for such system, $r = 1$ and the system reliability is

$R_{m1} = 1-(1-p)^m$ …………………..(16)

To compare the dependence of R on m, consider a system with (m+1) circuit breakers.

Let z be the ratio of the reliabilities of these two systems = R_{m+1}/R_m, so long as $z > 1$.

The system reliability increases with an increase in the number of circuit breakers.

Let $q = (1-p)$, then

$Z = r^{m+1} (1- q^{m+1}) / r^{m} (1 - q^{m})$ ……..(17)

Let $m = 1, 2, 3$…………

$Z_1 = r (1+ q)$

$Z_2 = r (1 + q^2 / 1+ q)$

$Z_3 = r (1 + q^3 / 1+ q + q^2)$

Similarly determine z4, z5 ………….etc.

It is evident that as m increases, the value of z decreases, since q is always less than one and therefore q^m decreases as m increases until $z > 1$ is obtained .The circuit breaker functioning with several protective devices at each stage in the circuit configuration being governed by the probability laws corresponding to its own variability factors.

Any attempt to reduce the variability will be increasing the cost and it is essential to compare the increased cost with the improvement in the reliability factor of the system.

6.0 Conclusion

This method proposed for enhancing the reliability of power system including the approach of successful path and failure path are useful for solving complex Interconnected Transmission line networks.

The system reliability is further increased due to the introduction of Distributed Generator (D) at the Intermediate Sub-Station as shown in figure 8.

The method developed for calculating the reliability for a sample two generator wind farm can be extended to large number of wind generators connected on the various network combinations in transmission lines to give uninterrupted power supply to the customers.

While the reliability of getting uninterrupted supply at the load is increased with each increase of Intermediate sub-station circuit breakers, but at the same moment, the probability of getting a false tripping message sent by accident or malfunctioning of breaker & its associated protective relays also increases. Consequently, in analyzing the system reliability, one has to take into consideration not only the probability of the system functioning satisfactorily at a time when it should, but also the probability of the system functioning, when it should not.

Therefore, in the process of designing an electrical system, the reliability of the system depends on a large number of parameters which directly affect the behavior of the system. These parameters in general are not deterministic but are governed by probability laws.

However, the novel techniques demonstrated in this paper for Circuit Breaker configuration in Transmission lines will be of immense help to the researchers & system planners in evaluating the system reliability.

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