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Effect of the Bus-Section and Generator-Breaker on Reliability Indices of Busbar Schemes in Power Plant

R. Hooshmand, M. Ataei and M. Moazzami
Department of Electrical Engineering, University of Isfahan, Isfahan, Iran

Abstract: One of the main subjects in power systems is increasing the power-plant reliability in emergency conditions. In power systems, the power-plant outage is considered as a critical position, which leads to economic damages and instability problems. Surely, the type of the busbar layouts in power stations affects the power-plant availability. In this study, the effect of the bus-section and generator-breaker in one and half-circuit breaker system and two-circuit breaker system and the effect of the above points over reliability parameters are investigated. For simulation, the cutest and path algorithm have been applied. Finally economical evaluations of the simulation results show the effectiveness of the bus-section and generator-breaker in busbar layout of power-plant substations.

Key words: Reliability, power plant substations, generator breaker, layout, circuit breaker

INTRODUCTION

The reliability in power systems as an important subject is usually considered significantly. One of the strategic and important points in power systems are the power-plants. The reliability in power-plants has a considerable effect on the reliability improvement and the stability of the power systems. Therefore, the performance of the power-plants with the highest possible availability has become one of very important subjects in recent years. Obviously, power-plant layouts have concrete effect on this subject. This has been caused the concentration on power-plant layouts to achieve the highest possible availability with the lowest cost and some modifications have been accomplished to improve the reliability in power-plants.

Braun *et al.* (2003) and Karlsson *et al.* (1997), the effect of the substation type, in the insulation point of view, for Air Insulation Substation (AIS) and Gas Insulation Substation (GIS) is investigated. Braun *et al.* (2003), the influence of the generator breaker on different types of the layout systems of high voltages substations and the effect of station transformers including Main Transformer (MT), Unit Transformer (UT) and Station Transformer (ST) and their numbers on the reliability of the busbar layouts of power-plant substations is also evaluated. Vega and Sarmiento (2008), the effects of active and passive failures of elements on the performance of power-plant layout system are examined. The influence of using advanced auto-diagnostic systems on the HV breakers for improving the reliability of power-plant busbar is presented by Guenzi and Politano (2003). The time variant loads have an impact on substations reliability, which is considered by Suwantawat and Premrudeeprechacharn (2004). The generator breaker has an impact on the faults occurrence in power transformer is presented by Culver *et al.* (1996).

An effect of the synchronous generator circuit breaker on the reliability of busbar layout in power plant substation in deregulated electricity market is investigated by Banejad *et al.* (2008). In this study, show that the synchronous generator circuit breaker increases the reliability indices as well as reducing the cost in the deregulated electricity markets. Regarding the importance of the reliability of the substations busbar layouts, usually in power-plant substations one and half and two-breaker busbar layouts are used. Using the generator breaker improves the power-plant availability and provides the possibility of direct plant auxiliaries to-be-fed from the main net (EHV, transmission system), which is more reliable than the reserve net (local sub-transmission system).

Moreover, interruption due to short circuit currents in generator-fed is reduced. Also, the damages due to faults in being out of service duration are reduced that increases the availability of the power-plant. In a sectionalized busbar the main bus is divided into two or more sections with a disconnector or a circuit-breaker and isolators, between the adjoining sections. One section can be completely shut-down for the purpose of bus

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Corresponding Author: R. Hooshmand, Hezar Jerib Street, University of Isfahan, P.O. Box 81746-73441, Isfahan, Iran

maintenance repairs or extension without disturbing the continuity of the other bus section. The numbers of sections depend on the importance of the station and local switching requirements.

In none of the above-mentioned references, the impact of the bus-section on the busbar layouts of power-plant is considered. The effect of the generator breaker is discussed by Braun *et al.* (2003), preliminarily such that its impact on the busbar layouts of power-plant is not presented. In what follows in this study, we will consider the impact of the bus-section and the generator breaker on the busbar layouts of power-plant simultaneously. Also, different cases with and without presence of the bus-section and the generator breaker is investigated. Economic evaluation of the different busbar layouts without extra elements and with generator and bus-section is considered. For simulation also, minimal cut and path sets algorithm is performed in which MATLAB package as a simulating tool is used.

THE SYSTEM MODEL

The overall view of the busbar layouts in one and half and two-breaker power-plants are shown in Fig. 1 and 2. The generator and transformer set are connected to the busbar layout through L11 and L12. The L21 and L22 lines are also external lines from busbar, which connect the power-plant to the main net. In Fig. 1 and in ordinary condition, generator breakers and bus sections aren't available. The configuration of one and half-breaker busbar that is usually used in power-plant substations has high reliability and flexibility. In this layout, three breakers are used for two feeders that all breakers are normally closed.

In this layout, even if one of the buses is failed, the transmission power is provided without any interruption. In addition, the configuration of two-breaker busbar, which is common in power-plant substations has very high reliability and flexibility. In this system, four breakers are used for two feeders.

Essentially, one and half and two-breaker systems are both expensive; however, two-breaker layout has higher expense with respect to one and half-breaker system. In two-breaker system, one of the breakers is often out of service.

THE PROPOSED ALGORITHM PROCEDURE

The calculation method of the reliability parameters for simulation is based on the minimal cut and path sets (Vega and Sarmiento, 2008).

Some terminologies are used in this method, which are introduced as follow:

Path: A forward way from one node to other nodes.

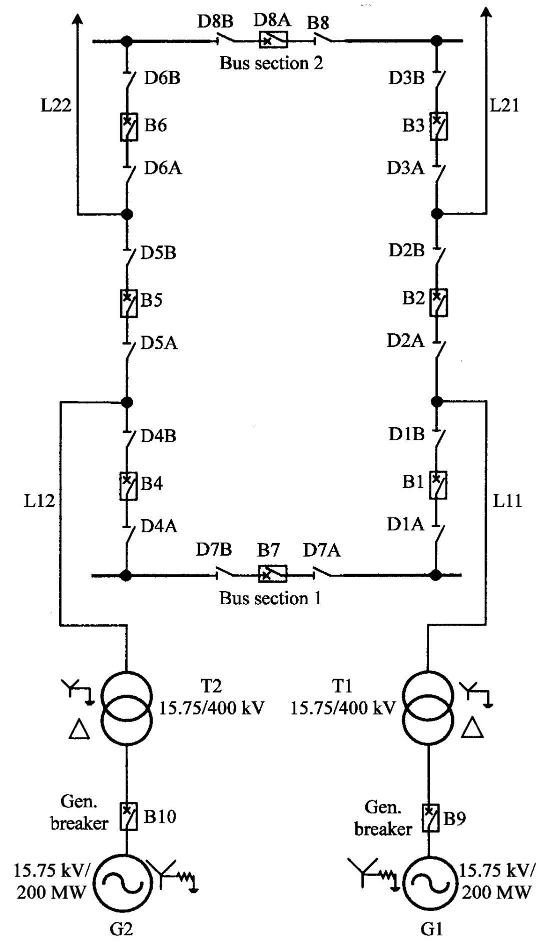

Fig. 1: One and half-breaker system with bus-section set 1 and 2 and the generator breaker

Minimal path: A path, which is started from a source node and is ended to load node such that it does not cross another node more than one time and does not produce any loop.

Basic minimal path: Minimal path in which each element is only connected to earlier or next element in the path.

Cutset: A set of branches in which if one branch cut, it causes the disconnection of the path between source node and sink node.

Minimal cutset: A set of the system elements, which if all of them are failed together, the overall system is failed. However, if only one of them is not failed, the overall system works correctly.

Tree: A path that is started from the source node and is ended to the sink node such that it contains all system elements and does not create any loop.

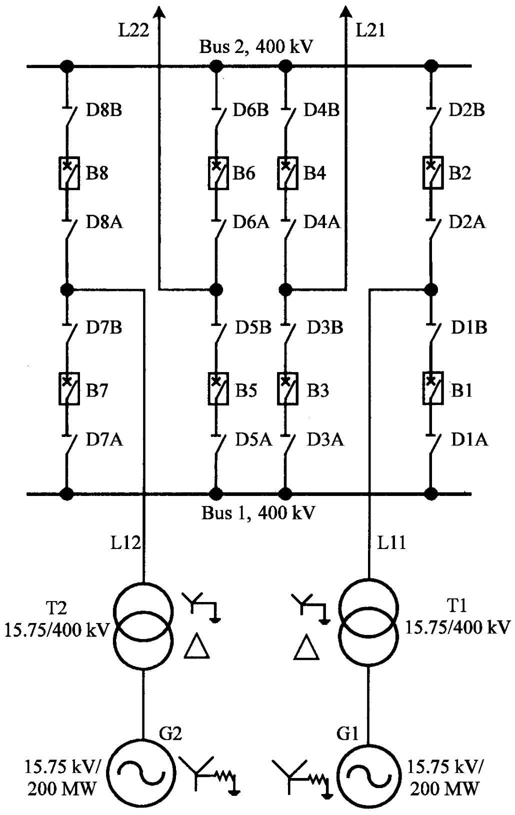

Fig. 2: The general schematic of busbar layout in two-breaker system

Failure rate (λ_i): The number of failures or outages of the ith element in a year.

Repair time (r_i): The outage time duration (in hour) of the ith element.

Unavailability (U_i): The amount of unavailability of the ith element (h year^{-1}).

The computation of the reliability algorithm has four stages as follows:

- Creation of the system graph model
- Determining the system paths and minimizing them
- Extraction of minimal cutsets
- Calculation of the reliability indices

Creation of the graph model of the system: For modeling of the system, at first, the sources are represented by a star (☆). The lines, transformer, breaker, disconnectors, load and bus are also modeled by a node (◯). The connection points are indicated by (0) and numbers of the output lines of the node are shown with the numbers outside (0). The load node is represented by a black circle (●). The normally open and close breakers have labels by NO and NC, respectively.

Determining the system paths and minimizing them: In order to find the path sets, the following steps are performed:

- Determining the tree
- Creating the paths
- Minimizing the paths

Step 1: Determining the tree: In the system graph, each tree starts from a source node and ends with a sink node. It should be noted that repetition of the branches is not permitted and the components of the path should not create any loop. This procedure is shown by a simple example.

In the graph of Fig. 3, the node 5 is a source node and node 1 is a sink node. Also, in Fig. 4, a tree structure is formed for the sink node 1, based on connection of components graph of Fig. 3.

Step 2: Creating the paths: Once, the tree is formed and completed, the paths can be found easily. All of the paths are:

1-2-3-4-3-2-..., 1-2-3-4-5, 1-2-5
1-4-3-2-3-4-..., 1-4-3-2-5, 1-4-3-5, 1-4-5

The paths 1-2-3-4-3-2-... and 1-4-3-2-3-4-... are not minimal, because of the recurrence of node 3 in the loop.

Step 3: Minimizing the paths: After eliminating non-minimal paths, basic paths are:

1-4-5, 1-2-5

The following paths are also eliminated, because the basic paths are subsets of them:

1-4-3-5, 1-4-3-2-5, 1-2-3-4-5

Now, the minimal cut-sets are extracted from the basic paths.

Extraction of minimal cut-sets: For determining the minimal cut-sets, the following terms are defined:

Passive failure: It is occurred when a component is failed. However, the failure of this element has not any effect on performance of the other elements.

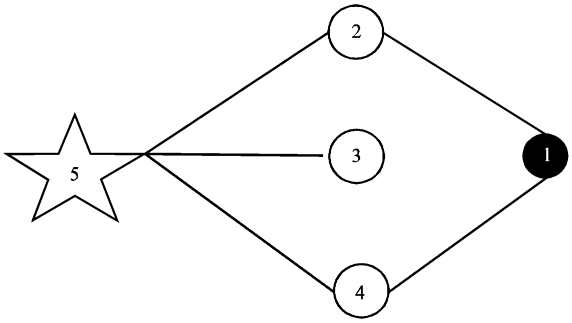

Fig. 3: The graph to show the determination of tree trajectories

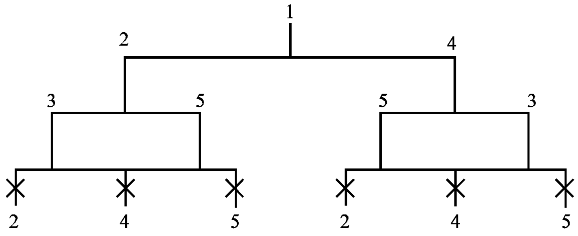

Fig. 4: Tree structure of graph system for sink node 1

Active failure: It is occurred when a component is failed and its failure has some effects on the performance of other elements.

Extraction first order passive failure cut-sets: In order to explain how the first order passive failure cut-sets is extracted; consider a sample system entitled as RBTS power system that is shown in Fig. 5. The graph model of Fig. 5 is shown in Fig. 6.

Regarding this graph, the basic paths are:

Basic path 1: 1-2-5-9-13-15-17-18

Basic path 2: 1-2-5-8-12-10-7-11-14-16-17-18

Basic path 3: 3-4-7-11-14-16-17-18

Basic path 4: 3-4-7-10-12-8-5-9-13-15-17-18

In all paths, each time that one node is appeared, one number is counted. Since, the number of appeared nodes in the paths is equal to the number of basic paths, these are first order passive cut-sets. For this example, nodes 17 and 18 are first order passive cut-sets.

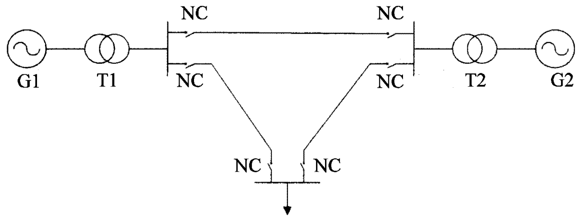

Fig. 5: A sample system entitled as RBTS power system

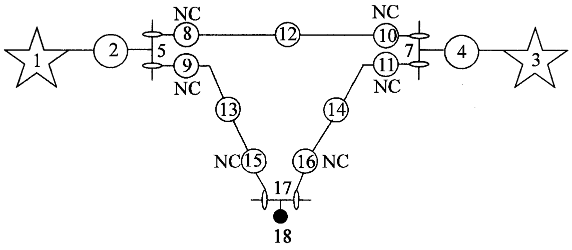

Fig. 6: The graph of the described system in Fig. 5

Extraction first order active failure cut-sets: In order to explain deduction of active first order failure cut-sets, the graph of Fig. 6 is used. At first, one sink node and its associated path are considered. Then other nodes in that path are found. Now, for each of these nodes, it should be examined that whether, the node is not a passive first order cut-set or is not a fictitious node or not a normally open node, or is not a sink node. If one or several nodes disconnect the path between the sink node and source node; those nodes are first order active cut-sets.

As mentioned before, in the graph of Fig. 6 the basic paths are:

Path 1: 1-2-5-9-13-15-17-18

Path 2: 1-2-5-8-12-10-7-11-14-16-17-18

Path 3: 3-4-7-11-14-16-17-18

Path 4: 3-4-7-10-12-8-5-9-13-15-17-18

Now, consider the node 18. For other nodes in path 1, the above-mentioned conditions are examined. The node 15 meets all of the requirements. This node is located in both paths 1 and 4. Also, node 15 is in the path of load 18 and also in two minimal paths. Regarding this, when a failure is occurred in node 15, the differential protective device operates and opens node 16. This operation leads to disconnection of all paths connected to the sink. Therefore, failure in node 15 is an active first order one. The other first order cut-set is 16.

Calculation of the reliability indices: The reliability indices are calculated by approximated methods and series and parallel formulas for cut sets. If the kth minimal path has m parallel elements, then the parameters of the equivalent element of this path are r_p, U_p and λ_p, which are calculated as follow (Billinton and Allan, 1984):

$$\frac{1}{r_p}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\cdots+\frac{1}{r_m} \tag{1}$$

$$U_p=(\lambda_1\cdot\lambda_2\cdot\ldots\cdot\lambda_m)(r_1\cdot r_2\cdot\ldots\cdot r_m) \tag{2}$$

$$\lambda_p=\frac{U_p}{r_p} \tag{3}$$

It should be noted that in Eq. 1-3, the values of r and λ are in hour and number of failures per year, respectively. Therefore, the value of U_p is given in h $year^{-1}$.

Now, the equivalent paths are series and after calculating the equivalent parameters of all paths, the final values of reliability indices are computed as follow:

$$\lambda_{total}=\sum_{k=1}^{n}\lambda_{pk} \tag{4}$$

$$U_{total}=\sum_{k=1}^{n}U_{pk} \tag{5}$$

$$r_{total}=\frac{U_{total}}{\lambda_{total}} \tag{6}$$

Economic evaluation of the busbar layouts: The other important subject in selecting the busbar layouts is the costs of the layouts and economic evaluation of the busbar. In order to compare different kinds of layouts, the total cost of layouts should be obtained and then annual cost is determined. For this purpose, considering the rate of growth of investment costs has significant importance; because, from the economical point of view an acceptable design is one whose productivity is more than the initial investment costs plus the growth rate of initial costs. Therefore, the initial costs including the costs of purchase, erection, lateral equipment and maintenance must be multiplied by the coefficient for capital turnover. That is

$$A_C=C\left[\frac{i(1+i)^n}{(1+i)^n-1}\right] \tag{7}$$

In Eq. 7, C is the total initial cost of the project (consist of initial cost, installation, reparations and maintenance), A_C is the annual cost, i stands for annual rate of growth of money and n for the life-span of the project (per years).

It should be noted that the effective factors in annually benefits are: the changes in system failure rate, the changes in time duration of equipments repairing, the maximum value of annually energy transferring from related layout and the cost of each kWh energy.

Therefore, it is seen that the cost of each plan, depend on the values of r and λ of each equipment significantly. In other words, the economic benefit is calculated as:

$$(U_2-U_1)\times P\times P_E$$

where:

U_2-U_1 = The decrement of the unavailability of the under consideration layout system
P = Transferred power from layout system in kW
P_E = Denotes the cost of each kWh energy

In the above economic analysis, the cost of the system life time consists of:

- Acquisition costs
- Civil work costs
- Installation costs
- Maintenance costs
- Ground costs

Where, in economic evaluation only the installation and maintenance costs have been considered and others are neglected.

RESULTS AND DISCUSSION

The initial data: In this study, the simulation results of the proposed algorithm is provided, which has been accomplished by MATLAB package. Figure 7 shows the algorithm flowchart. Each of considered system layouts has two bays in which there is one 200 MW generator with terminal voltage 15.75 kV and Y connection, one 15.75/400 KV transformer with Y and Δ connections (Y is in high voltage side) with apparatus power 250 MVA. In simulation procedure for each one and half-breaker and two-breaker layouts, five cases are considered in which the breakers are considered as active elements and others as passive elements. In this study, it is assumed that there aren't two simultaneous failure and stuck breaker.

The states which are considered are as follow:

Case No. 1: The busbar system without Bus-section in buses 1 and 2.

Case No. 2: The busbar system with only disconnector as bus-section in buses 1 and 2.

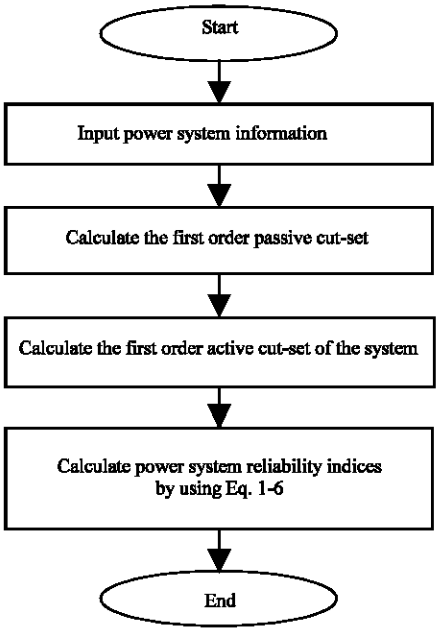

Fig. 7: Flowchart for the proposed methodology

Case No. 3: The busbar system with breaker and disconnector in both sides as bus-section in buses 1 and 2.

Case No. 4: The busbar system with circuit breaker and disconnector in both sides as bus-section in buses 1 and 2 and using the generator breaker in the generator terminal.

Case No. 5: The busbar system with the generator breaker in each generator terminal.

Regarding the importance of the generators breakers, here, the effect of this breaker is investigated individually. The reason of this importance is that, the generator breaker can significantly prevent from the possible dangers, especially explosion, in the generator transformers. It should be noted that the repairing of the main transformer in the case that the failure is not due to the explosion in the tank takes almost 1 month time and in the case of the tank explosion, it may take one year time. Therefore, using the generator breaker leads to reducing the MTTR.

The data of initial investing costs of the system elements, life cycle of the plan and the annual growth rate of the money are provided in Table 1. Moreover, the values of the r_i, λ_i and U_i, which are required for elements in the simulation are provided in Appendix A that is used also by Retterath *et al.* (2005), Suwantawat and Premrudeeprechacharn (2004), Billinton and Zhou (1997) and Endrenyi (1980).

Table 1: The related data for economic evaluation of the system

Variables	Values
Life cycle of plan (n)	30 years
Annual growth rate of money (i)	10%
Approximated cost of 400 kV breaker	165,000$
Approximated cost of the generator breaker with required nominal values	220,000$
Approximated cost of 400 kV disconnector	45,000$
Approximated cost of 1 kWh energy	0.06$

Table 2: The reliability indices for different one and half-breaker systems

Systems	λ_T (failure in year)	r_T (h)	U_T (h year^{-1})
1	0.0014	27.58	338.24
2	0.0014	26.57	325.85
3	0.0020	20.98	367.57
4	0.0018	19.65	309.84
5	0.0012	25.72	270.37

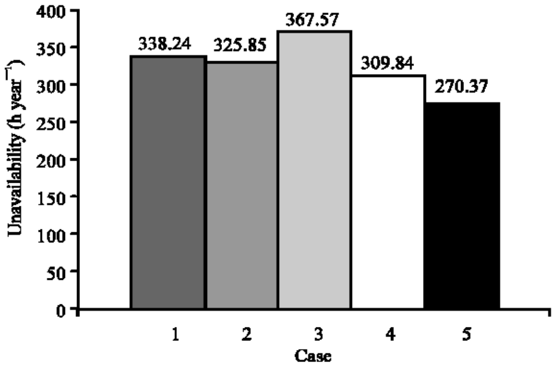

Fig. 8: Changes of unavailability in different cases at one and half circuit breaker system

The results for one and half-breaker system: The final simulation results of cases No. 1-5 for one and half-breaker system are provided in Table 2. Changes of unavailability in different cases are shown in Fig. 8.

In the cases No. 4 and 5, since the generator breaker is used the generator indices are improved which are given in Appendix A. The generator breaker with respect to usual breakers has less failure rate; however, its repair time is more than conventional breakers. The simulations in the cases No. 4 and 5 have been performed by considering the above mentioned points.

If the values of the case No. 1 in one and half-breaker system are considered as the base case and the others are compared with the first case, the results of the Table 3 are obtained.

The results for two-breaker system: Similar to the earlier subsection, the simulations are repeated for two-breaker system in all cases. The simulation results, that are the reliability indices of the overall system in different cases, are given in Table 4. Changes of unavailability in different cases are shown in Fig. 9.

Table 3: The variations of the reliability indices for simulation cases in one and half-breaker system

Systems	Changes of λ_T (%)	Changes of r_T (%)	Changes of U_T (%)
Case No. 1	Base	Base	Base
Case No. 2	0	-3.66	-3.66
Case No. 3	+42.86	-23.93	+8.67
Case No. 4	+28.57	-28.75	-8.39
Case No. 5	-14.29	-6.74	-20.06

+: Indicates the increment of the indices with respect to base indices, -: Indicates the decrement of the indices with respect to base indices

Table 4: The reliability indices for different two-breaker system

Systems	λ_T (failure in year)	r_T (h)	U_T (h year^{-1})
Case No. 1	0.0018	23.13	364.71
Case No. 2	0.0018	22.16	349.42
Case No. 3	0.0027	18.62	440.40
Case No. 4	0.0023	17.57	354.00
Case No. 5	0.0016	21.69	304.01

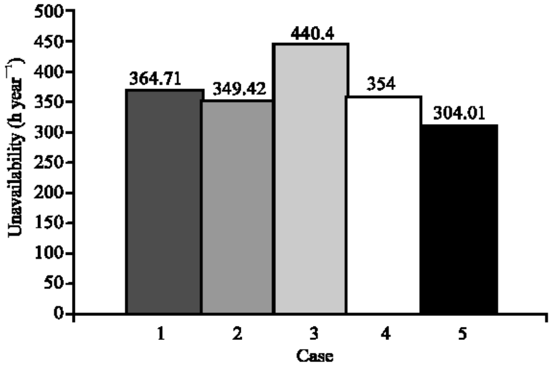

Fig. 9: Changes of unavailability in different cases at two circuit breaker system

In order to evaluate the different cases of two-breaker system with respect to each other, the values of the case No. 1 are considered as the base case and the other cases are compared with this base case. The comparison results are provided in Table 5.

Comparison of the results for two busbar layouts: By examining different simulation results, the following conclusions are achieved:

- The existence of only bus-section, reduces the repair time (r_T) significantly however, failure rate of the system (λ_T) is increased. The unavailability amount (U_T) has different changes such that in case No. 2 with respect to case No. 1 is decreased, but in case No. 3 is increased. The reduction of the repair time in the case that a set of breaker and disconnector are used is more considerable than the case of using only disconnector as bus-section
- Using the generator breaker and bus-section set, reduces the reliability indices of the case No. 4 with respect to No. 3, which implies the advantage of the generator breaker. The reduction of the system repair time is also significant

Table 5: The variations of the reliability indices for simulation cases in two-breaker system

Systems	Changes of λ_T (%)	Changes of r_T (%)	Changes of U_T (%)
Case No. 1	Base	Base	Base
Case No. 2	0	-4.19	-4.19
Case No. 3	+50	-19.50	+20.75
Case No. 4	+27.78	-24.04	-2.94
Case No. 5	-11.11	-6.23	-16.64

Table 6: The comparison results of the cases 4 and 1 for one and half-breaker system

Variables	Values
Changes of λ_T (failure year^{-1})	+0.0004
Changes of U_T (h year^{-1})	-28.4
Changes of r_T (h)	-7.93
The increment amount of investment in case 4 for one and half-breaker system with respect to case No. 1 of one and half-breaker system per year	Approximately 101,200$
The increment amount of benefits in case 4 for one and half-breaker system with respect to case No. 1 of one and half-breaker system per year	681,600$

Table 7: The comparison results of the cases 5 and 1 for one and half-breaker system

Variables	Values
Changes of λ_T (failure year^{-1})	-0.0002
Changes of U_T (h year^{-1})	-67.87
Changes of r_T (h)	-1.86
The increment amount of investment in case 5 for one and half-breaker system with respect to case No. 1 of one and half-breaker system per year	Approximately 47,000$
The increment amount of benefits in case 5 for one and half-breaker system with respect to case No. 1 of one and half-breaker system per year	Approximately 1,628,880$

+: Indicates the increment of the indices with respect to base indices; -: Indicates the decrement of the indices with respect to base indices

- Using only the generator breaker reduces all the reliability indices of the case No. 5 with respect to No. 1. In the case No. 5, in addition to improvement of the reliability indices, an economic benefit is also achieved. In the case No. 4, the simultaneous existence of the generator breaker and sub-section set, reduces the repair time excellently and also improves the unavailability amount of the layout system with respect to the case No. 1. But in case No. 5, though the repair time has less reduction with respect to case No. 1, the system failure rate is decreased significantly
- If case No. 1 of one and half-breaker system is considered as the base and cases No. 4 and 5 of one and half-breaker system is compared with it, the results are as shown in Table 6 and 7. By examining the results of the Table 6, it is seen that modified systems in addition to the improvement in the system reliability indices, have economic benefits as well.

If the case No. 1 of two-breaker system is considered as the base and cases No. 4 and 5 of two-breaker system is compared with it, the results will be as given in Table 8 and 9. It is concluded that the use of generator breaker in one and half breaker busbar layouts is more effective with respect to two-breaker system.

Table 8: The comparison results of the case 4 with respect to case 1 for two-breaker system

Variables	Values
Changes of λ_T (failure year^{-1})	0.0005
Changes of U_T (h year^{-1})	-10.71
Changes of r_T (h)	-5.56
The increment amount of investment in case 4 with respect to case 1 for two-breaker system	101,200$ per year
The increment amount of benefits in case 4 with respect to case 1 for two-breaker system	257,040$ per year

Table 9: The comparison results of the case 5 with respect to case 1 for two-breaker system

Variables	Values
Changes of λ_T (failure year^{-1})	-0.0002
Changes of U_T (h year^{-1})	-60.7
Changes of r_T (h)	-1.44
The increment amount of investment in case 5 with respect to case 1 for two-breaker system	47,000$ per year
The increment amount of benefits in case 5 with respect to case 1 for two-breaker system	1,456,800$ per year

+: Indicates the increment of the indices with respect to base indices; - : Indicates the decrement of the indices with respect to base indices

CONCLUSION

In this study, the impact of the bus-section and generator breaker in one and half and two-breaker busbar layouts was considered. The path and minimal cut set algorithm was applied for simulation by using Matlab package.

It was concluded that the existence of bus-section and the generator breaker improve the reliability indices and also has economic benefit. Moreover, it was seen that simultaneous usage of breaker and its disconnector as bus-section is more effective than using only disconnector. It was also concluded that the use of generator breaker in one and half-breaker busbar layout is more effective with respect to two-breaker system.

Appendix A: The parameters of the elements for studying the reliability of the busbar systems are shown in Appendix A:

Appendix A: The parameter values of the elements for simulations

Elements	λ_T (failure year^{-1})	U_T (h year^{-1})	r_T (h)
G1-G2	0.08	10	100
G1*-G2*	0.065	7.5	92
T1-T2	0.0153	5.5	192
L11-L12- L21-L22	0.01437	0.296	4.3
Breakers B1 … B8	0.015	1	70
B1*… B8*	0.015	0.9	65
Breakers B9, B10	0.008	0.8	110
Buses 1 and 2	0.01437	0.001	9.5
Disconnects D1 … D10	0.01	0.02	4

*The improved values of the reliability indices in two-breaker busbar system

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