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Selection of Busbar Schemes for Gridstations, A Mathematical and Graphic Approach

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INTRODUCTION

According to a reference (1) the installed capacity of power plants in 1947 at all places now comprising Pakistan was about 60 MW. Over the last 36 years there has been an enormous progress and the existing installed capacity including hydel, steam and nuclear power generation is 4,809 MW (ref.2), out of this WAPDA's part is 3,954 MW while REPCO and MESCO jointly have 29 MW capacity. Naturally the number of out-door substations, generally called gridstations here, increased from less than ten in 1947 to 415 in 1983 in WAPDA system alone, while the transformation capacity has become 11,854 MVA (ref.3).

TABLE 1: IN SERVICE GRID STATIONS AS ON 30.6.83

PROVINCE	500 kV		220 kV		132 kV		66 kV		TOTAL	
	No.	Capacity MVA	No.	Capacity MVA	No.	Capacity MVA	No.	Capacity MVA	No.	Capacity MVA
Punjab	1	900	7	1790	125	4595	124	1576	257	8861
Sind	-	-	-	-	43	851	35	306	78	1157
NWFP	-	-	1	320	25	659	32	372	58	1351
Baluchistan.	-	-	1	160	10	203	11	122	22	485
TOTAL:	1	900	9	2270	203	6308	202	2376	415	11854

In the Sixth Five Year Plan it is stipulated that "370 gridstations including extensions, augmentation and conversion will be set up and 7,000 MVA of additional transformation capacity will be provided".

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An idea as to how much more expansion in our power system is essentially required can be had from a simple fact that at present "only 22% of our population has access to electricity while many Asian Countries such as Taiwan and South Korea has almost 100% consumer saturation" (ref.4). The rural scene is more pinching as "at present only 8% of Pakistan's rural population has access to electricity. Also out of about 45,000 villages listed in the census of 1972, only 16,400 villages have been electrified in 35 years" (ref.5). Paucity of funds has been the main cause for this state of affairs (ref.16). WAPDA has announced to spend vast sums of money on outdoor substations and associated works during the coming years as shown in Table-2 (ref.6). In view of the huge cost for a substation it can be understood that the lion's share of the allocated funds shall be for substations (Annexure-A).

TABLE 2 : FINANCES REQUIRED FOR GRID STATION AND SECONDARY TRANSMISSION (MILLIONS OF RUPEES)

YEAR	1984	1985	1986	1987	1988	1989	1990
Finances allocated	1663	2095	1741	1550	1845	1750	1850

BUSBAR SCHEMES

Which particular busbar scheme should be selected for a substation is quite a vital question and creeps up at the preliminary stage of the design. The more intricated and sophisticated a scheme, the more expensive it will be, thus the relative importance of the substation, space and available budget are some of the important factors that dictate the selection. Although there are many busbar schemes including some traditional and a few hybrid (ref.7) yet the reasons for the development of abnormal designs are obscure.

A World Survey of substations was carried out some time back in London and the statistics compiled from the responses of more than 100 electricity companies revealed that the following 5 busbar schemes were in the forefront:

(1) Single busbar scheme with sectionaliser
(2) Double busbar scheme with buscoupler
(3) Main and transfer scheme
(4) Mesh scheme
(5) 1½ circuit breaker scheme

TABLE 3 : PERCENTAGE USE OF BUSBAR SYSTEM - ALL VOLTAGES (RESULTS OF THE WORLD SURVEY)

DESCRIPTION	NUMBER OF STATIONS	PERCENTAGE* USE	TYPE	
			Indoor%	Outdoor %
Single	779	53	29	88
Transfer	579	24	-	100
Double	912	80	33	95
Mesh	14	11	-	100
1½ C.B	8	7	33	100

(* Percentages are based on usage, and not on number of substations)

In Pakistan Single, Double and Transfer schemes are excessively used. Single bus being cheapest of all is specially favoured for rural areas where continuity of supply is not extremely important and even lesser degree of reliability is acceptable. Although one research paper from Sydney had claimed that "busbar faults are extremely rare and occur almost once in 40 years", (ref.8) yet the statistics gathered by the World Survey did not agree to this version. Another scheme, 1½ C.B., is also sometimes used (for example at Tarbela) specially at big power stations, but being extremely costly its use is very limited. Mesh scheme is rarely used in Pakistan though it is not

so rare in U.K. or U.S.A. Before 1947 this scheme was used in ULH RIVER SCHEME in one or two places but its performance proved a sorrow (ref.9). Inspite of its many advantages (ref.10), for developing systems where some more feeders may have to be installed in future selection of Mesh Scheme is "invitation to trouble" (ref. 9,11). In this country it has been used in BURHAN and a few more substations during the last 10-15 years.

In contrast to the present method of selection based on thumb-rule practice, in this paper a mathematical approach to the selection is offered and it is vindicated as to how many feeders will be out of service in the case of fault or maintenance. Consequently sufficient justification can be offered and it can be logically decided as to why a particular scheme should have an edge over the other.

BASIS OF THE MATHEMATICAL APPROACH

(a) Assessment of Reliability

As said earlier there are many factors that have to be kept in view while formulating the key diagram of a substation and one reference (15) has dealt with the subject in sufficient detail. However, some references have suggested that the reliability of a substation should be the yardstick to compare different busbar schemes. For instance if we have to compare two substations, one having single busbar scheme and the other having double busbar scheme, then we should ascertain the reliability of both and thus compare the results so obtained. Concisely it can be said that the reliability of supply during maintenance of faults is often the most important factor which dictates the selection of a particular scheme.

Over the recent years some concrete efforts have been made to ascertain the reliability of power stations and power systems as a whole by applying probability

theory, using Boolean algebra, the Markov process and computer simulation (ref. 12,13,14). Also one reference has specially focused his attention towards outdoor substations and determined the reliability by using the above mentioned mathematical tools (ref.15).

However, it can be added that the worth of such techniques is limited by the unpredictable nature of much of the data on which the authors of such references so firmly depend. For instance, the probability of fault occuring at a particular point in a substation depends on the reliability of apparatus, the degree of exposure to climatic and other hazards, the number of vulnerable items such as isolators involved and the layouts. Further the probability of fault occurring during the time period while maintenance is being carried out also adds to the elements of chance.

To sum up, what we gather from the above discussion is that the results so obtained may not be dependable.

(b) Evaluation of outages of circuits

The alternative approach is that we examine the problem in the perspective that in comparing busbar systems it is the effect of fault which should be taken into account rather than their probability. Further in a specific case, for instance in a particular substation, the probability factors are mostly constant. Hence it seems quite logical and rational that a comparison can be based on the assessment of possibilities of losing circuits. In this paper the latter approach is followed. Typical maintenance and fault conditions in single Busbar scheme with sectionaliser have been chosen to explain the method in detail. The results are then tabulated as well as plotted on a Graph Chart.

Conditions Selected for the Case Study

The following conditions are assumed for this particular study:

(i) Maintenance of any circuit breaker (C.B), isolator or busbar section.

(ii) A single fault on any circuit, circuit breaker or busbar section.

(iii) A single fault on any circuit, circuit breaker or busbar section during the maintenance of any circuit breaker.

Any other set of conditions can be assumed. Similar charts and tables can be formulated for other busbar schemes or to evaluate the influence of such features as by passing facilities and busbar sectionalising.

Case Study for Single Busbar Scheme

In Figure 1 a simplified single busbar system is shown. We shall examine it for the various conditions explained in the preceding paragraph.

Outage Due to Maintenance

(i) It is possible that any one of the 6 feeders is out of service for maintenance. This means that there are 6 possibilities of losing one circuit. It is written as 6/1 and recorded so in the relevant Table-4.

(ii) Let us consider that busbar isolator L, as shown in Fig 1, is under maintenance. Naturally all the 3 feeders connected to section A of the busbar will be out of service, thus there is one possibility of losing 3 circuits. The same thing will happen when isolator M is under maintenance. So in all there are two possibilities of losing 3 circuits (written as 2/3).

Outage Due to Faults

(i) Consider that there is a fault at location "a" in feeder No.3. Naturally the associated C.B. will trip and thus one feeder will be out of service. As there are 6 feeders in all, there are 6 possibilities of losing one circuit (written as 6/1).

(ii) When the fault is inside the C.B. of feeder No.3, it will travel to busbar section A and thus all the 3 circuits connected to section A will trip. Again it is possible that there is a fault in the C.B. associated with feeder No.4, consequently all the 3 feeders connected to section B of the busbar will trip. In all there are 6 possibilities of losing 3 feeders (written as 6/3).

(iii) In case of fault taking place in section A of the busbar, all the 3 feeders connected to it will trip. Similarly when a fault occurs on section B of the busbar, all the 3 feeders connected to it will trip. So in all there are 2 possibilities of losing 3 circuits (written as 2/3).

(iv) When there is a fault in busbar-section C.B. the immediate effect will be that all the 6 feeders will trip. Of course, later on with the help of busbar isolators both sections of the busbar can be operated. Thus there is one possibility of losing 6 feeders (written as 1/6).

TABLE 4: OUTAGE DUE TO MAINTENANCE

S.No.	EQUIPMENT UNDER MAINTENANCE	OUTAGE POSSIBILITY
1.	Feeder C.B. and Feeder Isolator	6/1
2.	Busbar Isolator and Section of Busbar.	2/3

TABLE 5: OUTAGE DUE TO FAULT

S.NO.	FAULT LOCATION	SINGLE FAULT AS PER PRE-DETERMINED CONDITIONS	
1.	Any feeder		6/1
2.	Feeder circuit breaker (shown as 'b' in Fig 1).	6/3	8/3
3.	Busbar (shown as 'c' in Fig 1)	2/3	
4.	Busbar-section C.B. (shown as 'd' in Fig 1)		1/6

(* Possibilities with common denominators are added)

Outage Due to Fault During Maintenance

This aspect is examined for two conditions each of which is seen in detail.

(a) Fault during Maintenance of Feeder Circuit Breaker

(i) Consider that feeder No.1 is already out for maintenance and the remaining 5 feeders are in service. Suddenly there is a fault in feeder No.2 and it trips. Consequently two feeders have now become out of operation. As the fault can occur on any one of the five feeders (No.2,3,4,5,6) there are 5 possibilities of losing 2 circuits.

It is interesting to note that, as shown in Fig.2, there will be 30 possibilities of losing 2 circuits.

(ii) Let us see as to what happens when there is a fault in a feeder C.B. 'b'. Two cases can arise:

° When the fault occurs in the same section in which a feeder was already out for maintenance. Assume that feeder No.1 is out of service for maintenance and a fault occurs in the C.B. associated with feeder No.2. The result will be that all the

feeders connected to section A of the busbar will trip. It is easy to ascertain that there will be 2 possibilities of losing 2 feeders.

° When a feeder is out of service, for maintenance, in section A but a fault occurs in any of the feeders connected to section B.

Suppose feeder No.1 is out of service for maintenance and a fault occurs inside a C.B. associated with feeder No.4. The immediate result will be that all the 3 feeders connected to section B will trip and thus 4 feeders will be out of service. It is possible that the fault can take place in any of the C.B. connected to feeder No.4,5 or 6. Thus there are 3 possibilities of losing 4 circuits.

As per the theory of probability, the outage possibilities will be 3/3. It is interesting to know that in all tnere will be 18 possibilities of losing 3 feeders.

(iii) When a feeder is already out of service for maintenance and a fault occurs on the busbar there are two courses open:

When a feeder connected to busbar section A (Fig.1) is out for maintenance and a fault occurs in section A, the result will be that all the three feeders connected to busbar section A will trip. Hence there is one possibility of losing 3 circuits.

° When a feeder connected to busbar section A (Fig.1) is out for maintenance and a fault occurs in section B, the result will be that all the 3 feeders connected to section B will trip. Thus in all 4 feeders will be out of service. So there is one possibility of losing 4 circuits.

According to the theory of probability there will be 4 possibilities of losing 4 circuits when the above said two results are dealt with on cumulative basis. Further when it is considered that there are 6 feeders, the outage possibilities will become 24/4 (i.e. 24 possibilities of losing 4 circuits).

(iv) When feeder No.1 is already out for maintenance and a fault occurs in busbar section C.B.'d', the immediate result will be that all the 6 feeders connected to the busbar will trip. Thus there will be 1 possibility of losing 6 feeders.

It is easy to ascertain that in all there will be 6 possibilities of losing 6 circuits.

(b) Fault during Maintenance of Busbar Section Circuit Breaker

As above we shall deal this too for the various conditions.

(i) The busbar section C.B. is under maintenance, then both the sections of the busbar i.e. section A and section B will operate in isolation. Suppose there is a fault in feeder No.1 and it trips; it is possible that a fault can occur on any of the feeders thus there are 6 possibilities of losing one circuit.

It may be pointed out, by the way, that had there been two section C.Bs.the total possibilities of outages would have been 12.

(ii) Consider that a fault has occured in the C.B. of feeder No.3 (see Fig.1). The immediate result will be that all the 3 feeders connected to section A of the busbar will trip. In all there are 6 possibilities of losing 3 feeders.

(iii) In case of fault taking place in section A of the busbar, all the 3 feeders connected to it will trip. Similarly all the 3 feeders connected to busbar section B will trip. Thus there are 2 possibilities of losing 3 circuits.

The results gathered from the above discussion are recorded in the following table:

TABLE 6 : OUTAGE DUE TO FAULT DURING MAINTENANCE

Fault Location.	Fault during maintenance of feeder C.B.			Fault during maintenance of busbar section C.B.			All outage possibilities
	Outage (2)	No. of feeders (3)	Total outage possibilities (4)	Outage (5)	No. of section (6)	Total outage possibilities (7)	(8) = (4)+(7)
i) Any Feeder	5/2	6	30/2	6/1	1	6/1	30/2+6/1 +26/3+
ii) Feeder C.B. (b) Fig.1	3/3	6	18/3	6/1	1	6/3)) 8/3*	24/4+6/6
iii) Busbar (c) Fig.1	4/4	6	24/4	2/3	1	2/3)	
iv) Busbar Section circuit breaker.	1/6	6	6/6	-	-	-	

* Terms with common denominators are added.

CHARTS

In the end the various results gathered and tabulated in the preceding tables are exhibited on charts to demonstrate as to how many feeders will trip under some fault or maintenance conditions and how many of these can be reinstated. For brevity considerations only a few points from the charts are explained.

So far as Chart No.1 is concerned, which is based on Table-4, it is easy to understand that during the time a feeder is under maintenance, it cannot be reinstated, this means that a feeder will remain out of service as long as the maintenance is not over.

Regarding Chart No.2, which is based on Table-5, only the case of fault taking place in the section C.B. is explained; the immediate effect of the fault will be that all the 6 feeders will trip. However, by opening the two busbar isolators the defective C.B. can be isolated from the circuit and then all the 6 feeders can be reinstated.

CONCLUSION

In contrast to the existing practice of selection of busbar schemes which is mainly based on personal liking or disliking, a scientific approach founded on mathematics and logic is presented. Some charts are also formulated to exhibit the results; however, these will be of much more value when charts for different busbar schemes are constructed and compared. For example when Double busbar scheme is to be compared to Transfer bus scheme, charts for both schemes should be formulated and compared, and in no time it will become vivid as to which scheme has more reliability.

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ANNEXURE-A

COST ESTIMATION AS OF 1981

GRID STATIONS

(Million Rs)

S.No.	I t e m	MVA	Local	F.E.C.	Total
1.	132/11 KV Terminal Type Grid Station	20/26	10.32	5.67	15.99
2.	132/11 KV Terminal Type Grid Station	10/13	9.76	4.98	14.74
3.	132/11 KV Intermediate Grid Station having one transformer bay, one line isolator bay, one line bay.	20/26	11.20	6.23	17.43
4.	132/11 KV Intermediate Station having one transformer bay, one line isolator.	10/13	10.57	5.54	16.11
5.	66/11 KV Terminal Type Station.	10/13	7.61	3.20	10.81
6.	66/11 KV Intermediate Grid Station having one transformer bay, one line isolator bay, one line bay.	10/13	8.23	3.40	11.63

SOURCE:WAPDA

LIST OF FIGURES

Figure No.	T i t l e
1.	Single Busbar Scheme showing Fault in Different Locations.
2.	Number of Possible Outages
3.	Charts Showing the Various Outage Possibilities.

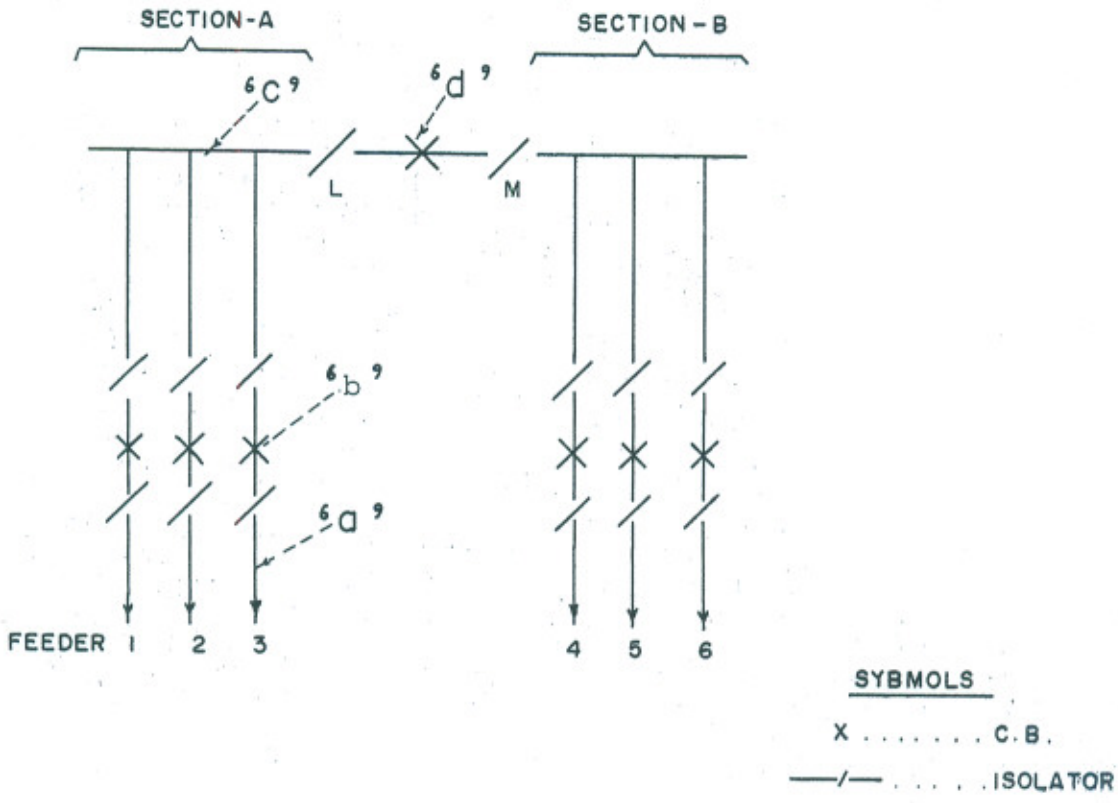


FIGURE-1

Single Busbar Scheme showing Fault in Different Locations

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x	0	0	0	0	0
1	2	3	4	5	6
0	x	0	0	0	0
1	2	3	4	5	6
0	0	x	0	0	0
1	2	3	4	5	6
0	0	0	x	0	0
1	2	3	4	5	6
0	0	0	0	x	0
1	2	3	4	5	6
0	0	0	0	0	x
1	2	3	4	5	6

FIG 2: NUMBER OF POSSIBLE OUTAGES

Explanation:

In the top row feeder No.1 is out for maintenance but fault can take place on any of the other five feeders. Hence there are 5 possibilities of losing 2 circuits. In the second row feedr No.2 is out for repair and again there are 5 possibilities of losing 2 circuits. It is clear that for each discrete case there are 5 possibilities of losing 2 feeders. Hence overall there are 30 possibilities of losing 2 circuits.

CHARTS SHOWING THE VARIOUS OUTAGE POSSIBILITIES

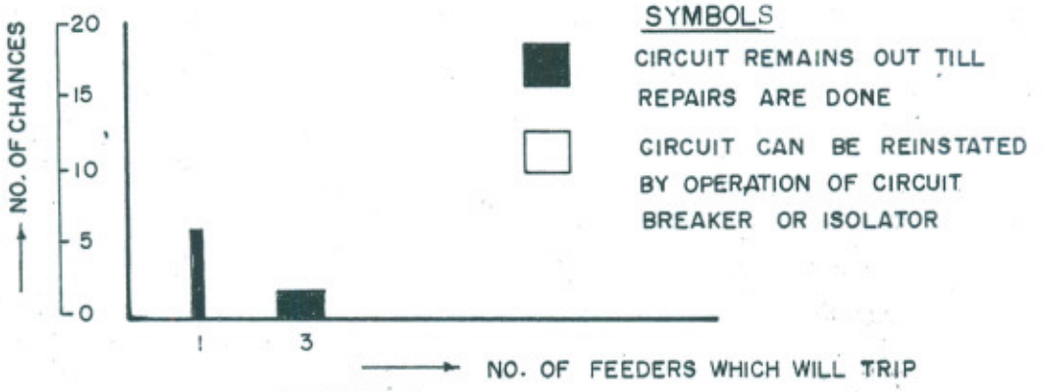
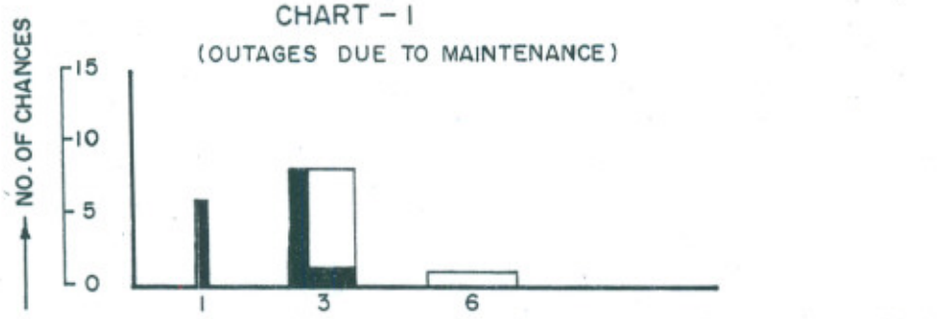


CHART – 1
(OUTAGES DUE TO MAINTENANCE)



CHART–2
(OUTAGES DUE TO FAULT)

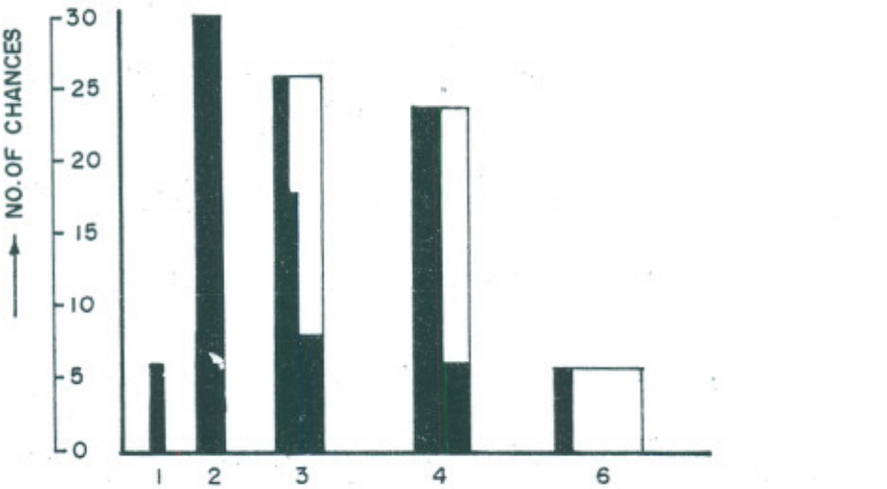


CHART – 3
(OUTAGES DUE TO FAULT AND MAINTENANCE)