CHAPTER FOUR

RESULTS OF SUBSTAION DESIGN

4.1 planning results

The planning study includes determining site location, and dimension substation's area as sown in Figure 4.1, also measuring of shortest path to substation as shown in Figure 4.2. Then calculating recent load, forecasting load after 10years from 2018 and number of feeders as shown in Table 4.1.

Figure 4.1: location of substation

Figure 4.2: Shortest path to substation

Table 4.1: Results of planning

Variable	Result of calculation
Length of path	3 km
Dimension of area	$10 \times 12\ m^2$
Recent demand	120.5 MVA
Forecasting demand	260 MVA
Transformer	Two main transformers110/33/11 KV with capacity of 150 MVA and star, star, delta connection, two Zigzag transformer 11/0.415 KV with capacity 1MVA delta , star connection
Number of feeders	6

From above planning results cable used to interconnect between MOG substation and S.H substation because area of center of Khartoum is very crowded and it's difficult to use overhead lines. Since S.H substation has small area so GIS type was selected. Depending on recent load forecasting load was calculated and capacity of transformers selected then numbers of feeders determined.

4.2 load flow results

To design the substation, load flow analysis is performed and bus voltages limits is shown in Figure 4.3, magnitude and angle of bus bar voltages are shown in Table 4.2, transformers loading in MVA and percentage is shown in Table 4.3, currents in buses are obtained in Table 4.4, transformer branches current are shown in Table 4.5, feeders current are obtained in Table 4.6 and incoming cables currents are obtained in Tables 4.7

4.2.1 Voltage level at buses

The marginal and critical limits which input in E-Tab program according to national electric standard as shown in Figure 4.3

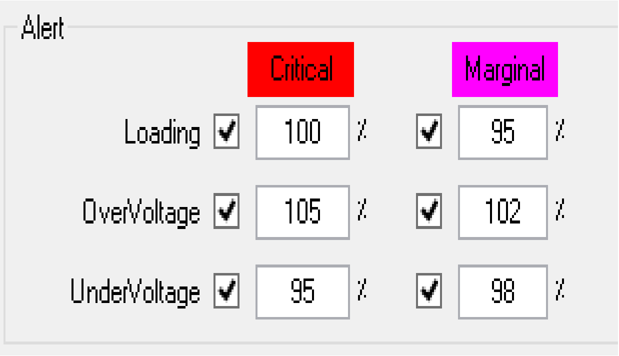

Figure 4.3: Marginal and critical limits of voltage

Load flow results of voltage magnitude and angle shown in Table 4.2

Table 4.2 Buses voltage magnitude and angle

Bus	Voltage(KV)	Angle(degree)
S.H 0.415KV(1)	0.396	-11.2
S.H 0.415KV(2)	0.397	-11
S.H 11KV(1)	11.35	-5.3
S.H 11KV(2)	11.316	-5.5
S.H 33KV(1)	34.423	-4.3
S.H 33KV(2)	34.316	-4.5

busbar voltages are within limits no fear of under or over voltage. Then the system is working healthily.

4.2.2 transformers loading

Load flow results of transforms loading are shown in Table 4.3

Table 4.3 Transformers loading in MVA and percentage loading

Transformer	Loading (MVA)	Percentage loading %
TR.AUX.1	0.940	75.2
TR.AUX.2	0.940	75.2
TR1.P	133.829	71.4
TR1.S	101.761	54.3
TR1.T	25.761	50.7
TR2.P	134.486	71.7
TR2.S	101.618	54.2
TR2.T	25.714	51.4

As seen in Table 4.3 all transformers meet the demand without suffering from under or overload.

4.2.3 current flow and CT ratio

Currents flow in buses, transformer branches, incoming cables and feeders are determined from load flow simulation result and according to these primary ratings of CTs ratios are determined based on IEC standard since secondary of CTs has constant value equal one in our national standard.

Current flow in buses and CTs ratios are shown in Table 4.4

Table 4.4 Buses current and CT ratio

Bus	Current(A)	CT ratio
S.H 0.415KV(1)	1271	1400:1
S.H 0.415KV(2)	1268	1400:1
S.H 11KV(1)	1242	1400:1
S.H 11KV(2)	1304	1400:1
S.H 33KV(1)	1772	2000:1
S.H 33KV(2)	1708	2000:1

Current flow in transformers branches and CTs ratios are shown in Table 4.5

Table 4.5 Transformers branches currents flow and CT ratio

Transformer	Current(A)	CT ratio
TR.AUX.1	47.95	100:1
TR.AUX.2	47.82	100:1
TR1.P	714	800:1
TR1.S	1772	2000:1
TR1.T	1201	1400:1
TR2.P	683.3	800:1
TR2.S	1644	2000:1
TR2.T	1304	1400:1

Current flow in feeders and CTs ratios are shown in Table 4.6

Table 4.6 Currents of feeders and CT ratio

Feeder	Current (A)	CT ratio
Feeder A	683.1	800:1
Feeder B	512.3	600:1
Feeder C	512.3	600:1
Feeder D	512.3	600:1
Feeder E	512.3	600:1
Feeder F	683.1	800:1
Feeder G	1242	1400:1
Feeder H	1236	1400:1
Feeder I	1268	1400:1
Feeder j	1271	1400:1

Current flow from incoming cables and CTs ratios are shown in Table 4.7

Table 4.7 incoming cables current and CT ratio

Incoming	Current (A)	CT ratio
Cable 1	705.8	800:1
Cable 2	702.4	800:1

4.3 Short-Circuit Results

Four different types of short circuit currents are calculated for all buses. Different cases are set up so that each bus can have a worst case scenario with the maximum short-circuit currents affecting each bus. The tested buses are 110Kv, 33kV ,11kV, and 0.415KV.

Summarizes the objectives of determining short circuit currents in power systems as shown in Table 4.8

Table 4.8 Objectives of short circuit currents in power systems

Item	Design Criterion	Physical Effect	Relevant short circuit current
1	Breaking capacity of circuit breakers	Thermal stress to Arcing chamber; arc extinction	Symmetrical short-circuit breaking current I_b
2	Mechanical stress to Equipment	Forces to electrical devices (e.g. bus bars, cables…)	Peak short-circuit current I_p
3	Thermal stress to Equipment	Temperature rise of electrical devices (e.g. cables)	Initial symmetrical short circuit current I_k'' Fault duration

Item	Design Criterion	Physical Effect	Relevant short circuit current
4	Protection setting	Selective detection of short circuit current	Minimum symmetrical short-circuit current I_k
5	Earthling, Interference, EMC	Potential rise Magnetic fields	Maximum initial symmetrical short-circuit

4.3.1 Maximum fault level at normal operation

At normal operation all bus tie breakers are opened as shown in Figure 4.4

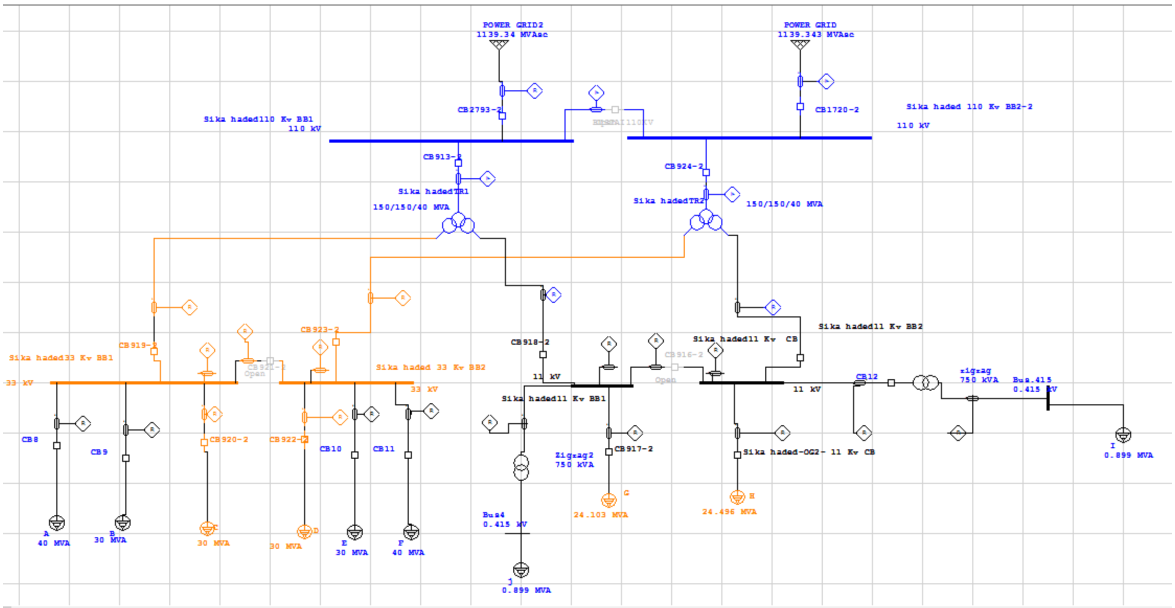

Figure 4.4: Substation at normal operation

I_k'' is taken from different types of faults at normal operation and shown in Table 4.9

Table 4.9 Faults levels of normal operation

Bus	I_k''(KA)			
	Three phase fault	Line to ground fault	Line to line fault	Line to line to ground
S.H11KV(1)	21.686	22.238	18.780	22.154
S.H 11KV(2)	21.794	22.314	18.874	22.246
S.H 33KV(1)	22.596	27.148	19.545	27.209
S.H 33KV(2)	22.429	27.942	19.425	27.003
S.H 110KV(1)	8.931	10.769	7.735	10.292
S.H 110KV(2)	8.8905	10.730	7.707	10.254
S.H 0.415KV(1)	22.178	19.433	19.207	21.693
S.H 0.415KV(2)	22.174	19.431	19.203	21.689

This Figure4.5 shows values of short circuit currents(I_k'' KA) at 11 KV bus bar at normal operation

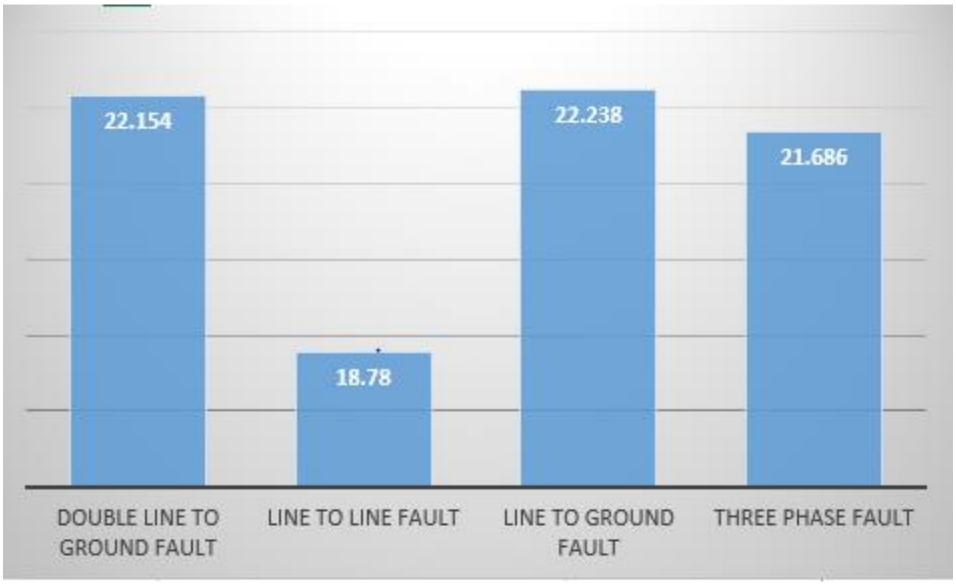

Figure 4.5: Comparison between different short circuit current at 11kv

The highest value of I_k'' KA short circuit current in 11KVbusbar is a line to ground fault with a value of 22.38 KA

This Figure4.6 shows values of short circuit currents(I_k'' KA) at 33 KV busbar

Figure 4.6: Comparison between different short circuit current at 33kv

The highest value of I_k'' KA short circuit current in 33KVbusbar is a line to ground fault with a value of 27.942 KA

This Figure4.7 shows values of short circuit currents(I_k'' KA) at 110 KV busbar

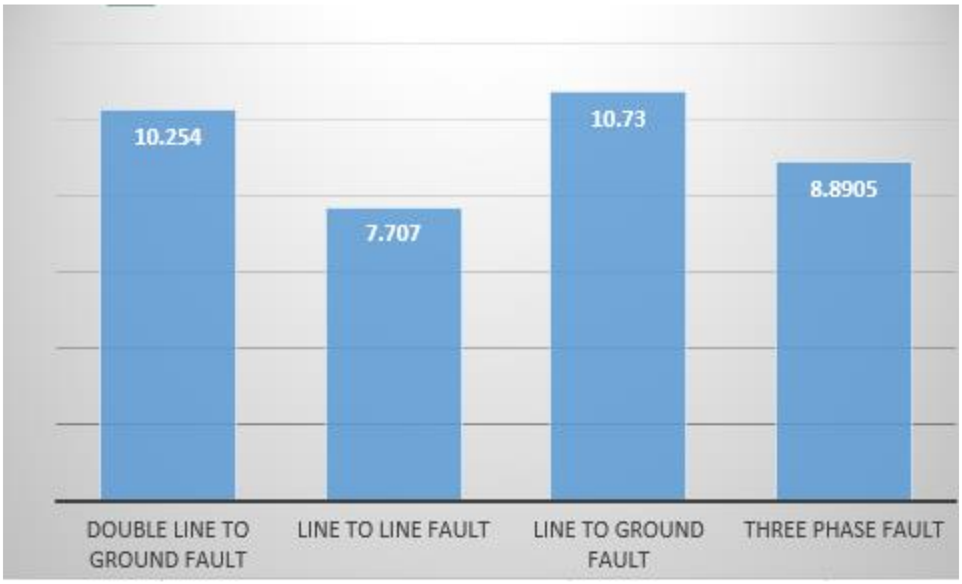

Figure 4.7: Comparison between different short circuit current at 110kv

The highest value of I_k'' KA short circuit current in 110KVbusbar is a line to ground fault with a value of 10.73 KA

This Figure4.8 shows values of short circuit currents(I_k'' KA) at 0.415 KV busbar

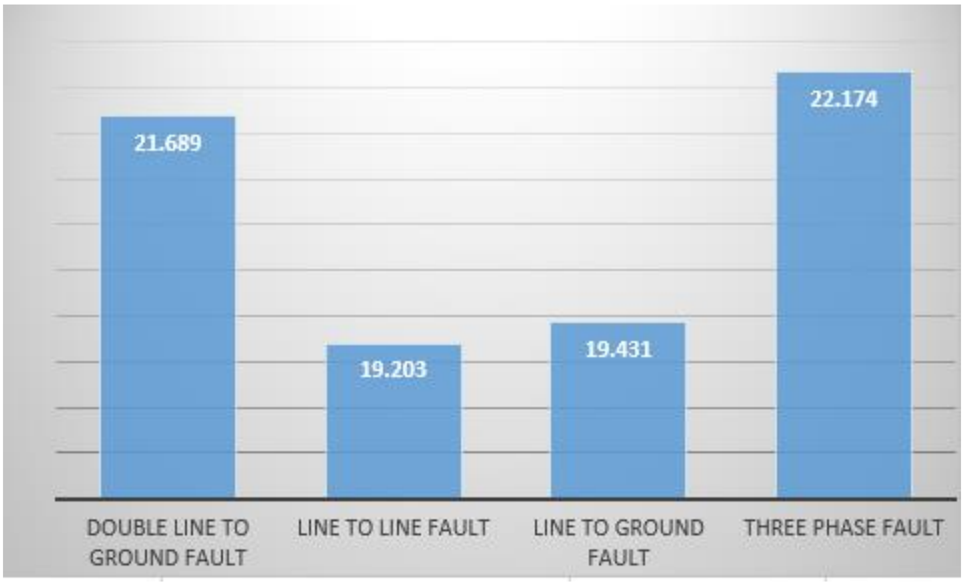

Figure 4.8: Comparison between different short circuit current at 0.415kv

The highest value of I_k'' KA short circuit current in 0.415KV busbar is a three phase fault with a value of 22.174 KA

The values of rated current, maximum fault current and AC breaking of circuit breakers at normal operation are shown in Table 4.10

Table 4.10 Rated current, maximum fault current and AC breaking of circuit breakers at normal operation

Breaker	Rated current(A)	Max fault current(KA)	AC breaking(KA)
At buses 11kv	1600	22.314	25
At buses 33kv	2000	27.942	31.5
At buses 110kv	800	10.730	12.5
At buses 0.415	1600	22.178	25

From load flow results currents flowing in buses helped in choosing rated current according to IEC standard, and from short circuit highest fault currents were considered in determining breaking capacity of circuit breakers at all buses.

4.3.2 Maximum fault level at parallel (1) operation

At parallel operation (1) bus tie of busbar 110 kv is closed as shown in Figure 4.9

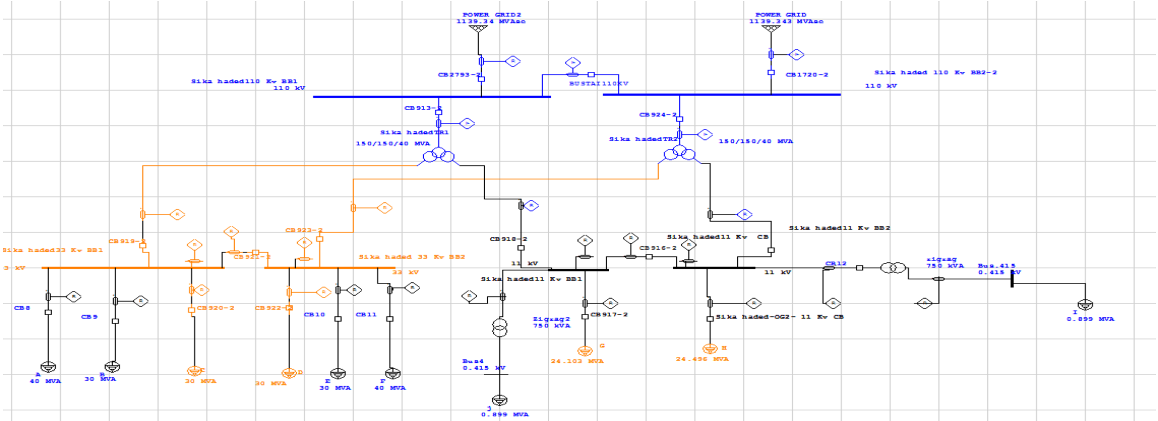

Figure 4.9: Substation at parallel (1) operation

I_k'' is taken from different types of faults at parallel (1) operation and shown in Table 4.11

Table 4.11 Faults levels of parallel (1) operation

Bus	I_k''			
	Three phase fault	Line to ground fault	Line to line fault	Line to line to ground
S.H 11KV(1)	43.480	44.551	37.655	44.400
S.H 11KV(2)	43.480	44.551	37.655	44.400
S.H 33KV(1)	45.001	56.094	38.972	54.216
S.H 33KV(2)	45.001	56.094	38.972	54.216
S.H 110KV(1)	17.831	21.500	15.442	20.547
S.H 110KV(2)	17.831	21.500	15.442	20.547
S.H 0.415KV(1)	22.279	19.489	19.294	21.774
S.H 0.415KV(2)	22.275	19.482	19.291	21.771

This Figure4.10 shows values of short circuit currents(I_k'' KA) at 11 KV bus bar at parallel(1) operation

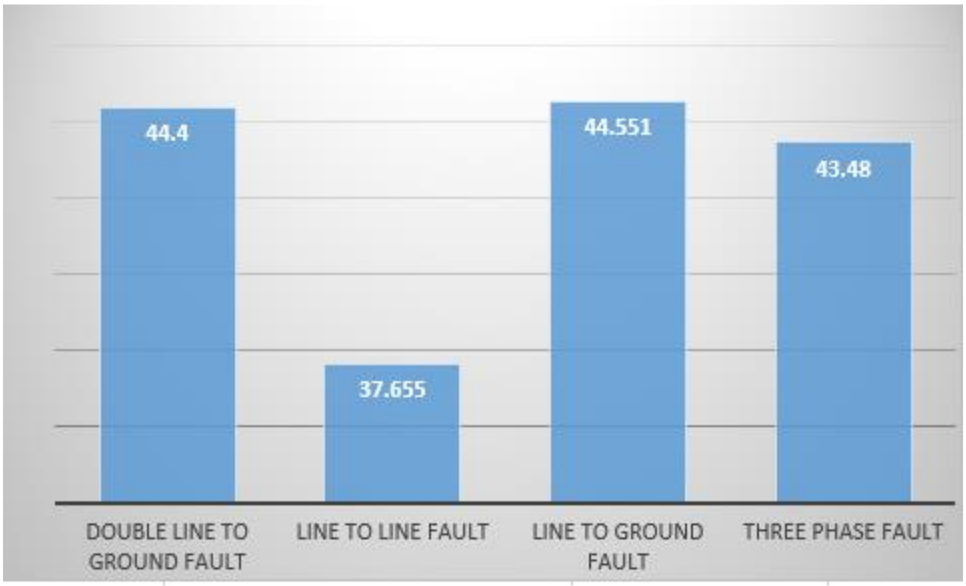

Figure 4.10: Comparison between different short circuit current at11kv at parallel operation (1)

The highest value of I_k'' KA short circuit current in 11KVbusbar is a line to ground fault with a value of 44.551 KA

This Figure4.11 shows values of short circuit currents(I_k'' KA) at 33 KV bus bar at parallel(1) operation

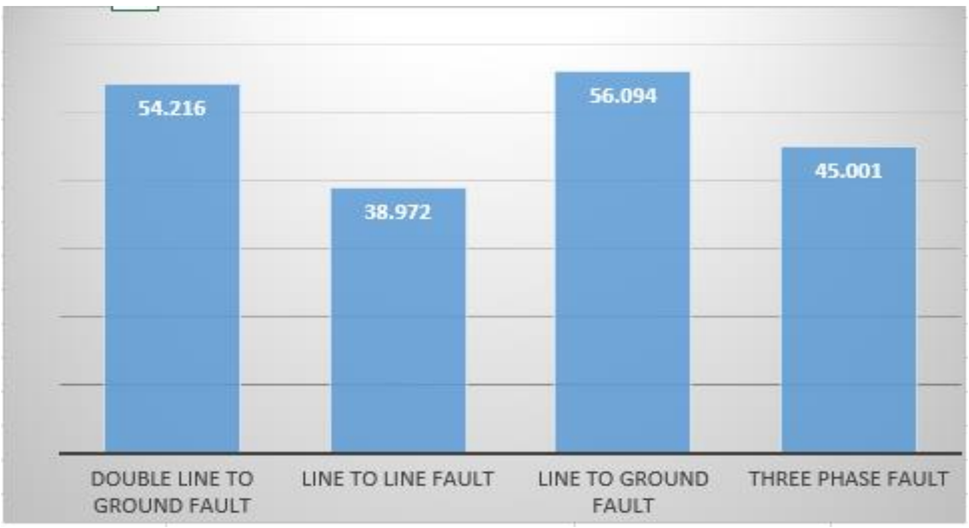

Figure 4.11: Comparison between different short circuit current at 33kv at parallel operation (1)

The highest value of I_k'' KA short circuit current in 33KVbusbar is a line to ground fault with a value of 56.094 KA

This Figure4.12 shows values of short circuit currents(I_k'' KA) at 110 KV bus bar at parallel(1) operation

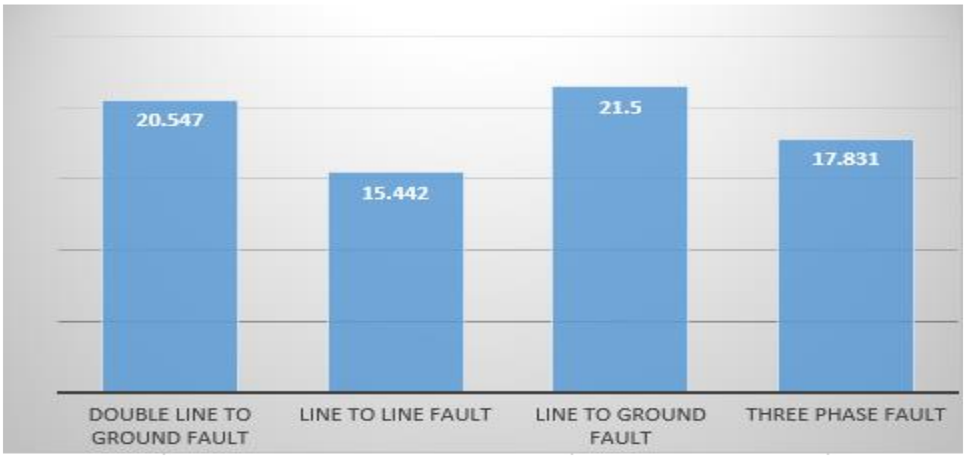

Figure 4.12: Comparison between different short circuit current at110kv at parallel operation (1)

The highest value of I_k'' KA short circuit current in 110KVbusbar is a line to ground fault with a value of 21.5 KA

This Figure4.13 shows values of short circuit currents(I_k'' KA) at0.415 KV bus bar at parallel(1) operation

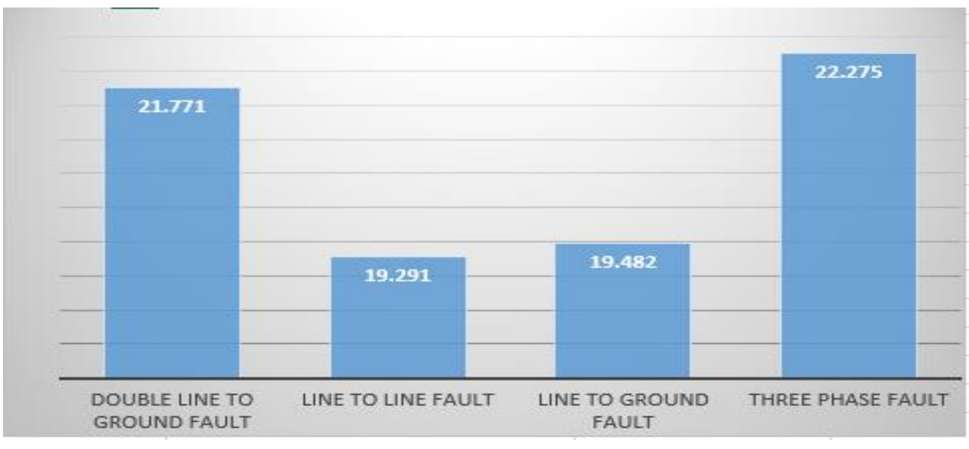

Figure 4.13: Comparison between different short circuit current at 0.415kv at parallel operation (1)

The highest value of I_k'' KA short circuit current in 0.415KV busbar is a three phase fault with a value of 22.275 KA

4.3.2 Maximum Fault Levels at parallel (2) operation

At parallel operation (2) all bus tie breakers at level 110kv,33kv and 11kv are closed and shown in Figure 4.14

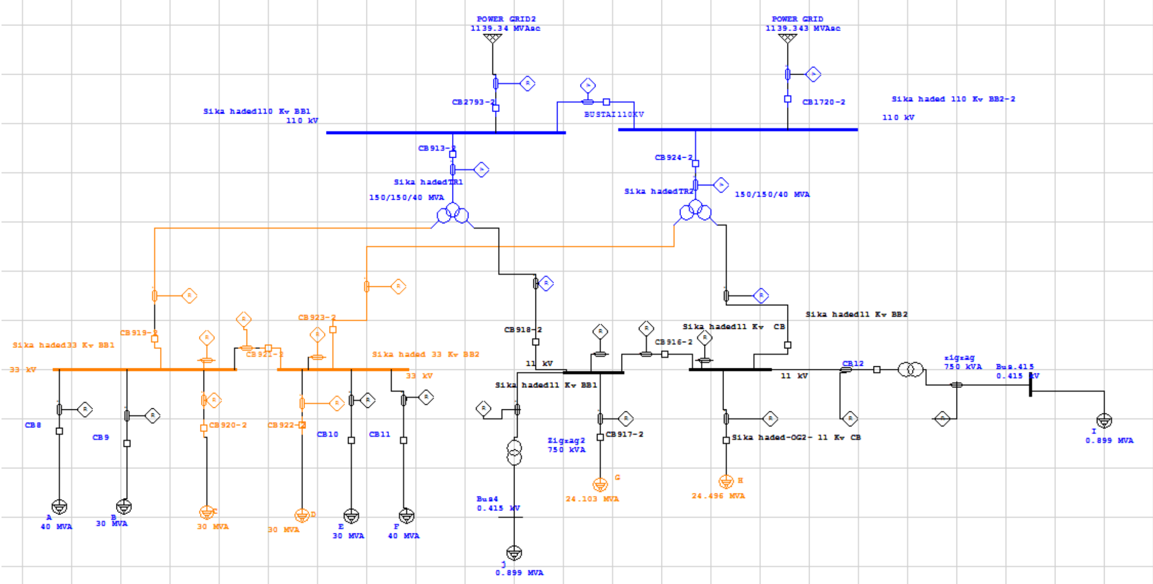

Figure 4.14: Substation at parallel (2) operation

I_k'' is taken from different types of faults at parallel (2) operation and shown in Table 4.12

Table 4.12 shows faults levels of parallel (2) operation

Bus	I_k''			
	Three phase fault	Line to ground fault	Line to line fault	Line to line to ground
S.H 11KV(1)	43.480	44.551	37.655	44.400
S.H 11KV(2)	43.480	44.551	37.655	44.400
S.H 33KV(1)	44.895	55.985	38.880	54.110

Bus	I_k''			
	Three phase fault	Line to ground fault	Line to line fault	Line to line to ground
S.H 33KV(2)	44.895	55.985	38.880	54.110
S.H 110KV(1)	17.817	21.486	15.430	20.533
S.H 110KV(2)	17.817	21.486	15.430	20.533
S.H 0.415KV(1)	22.279	19.484	19.299	21.774
S.H 0.415KV(2)	22.275	19.482	19.291	21.771

This Figure4.15 shows values of short circuit currents(I_k'' KA) at 11 KV bus bar at parallel(2) operation

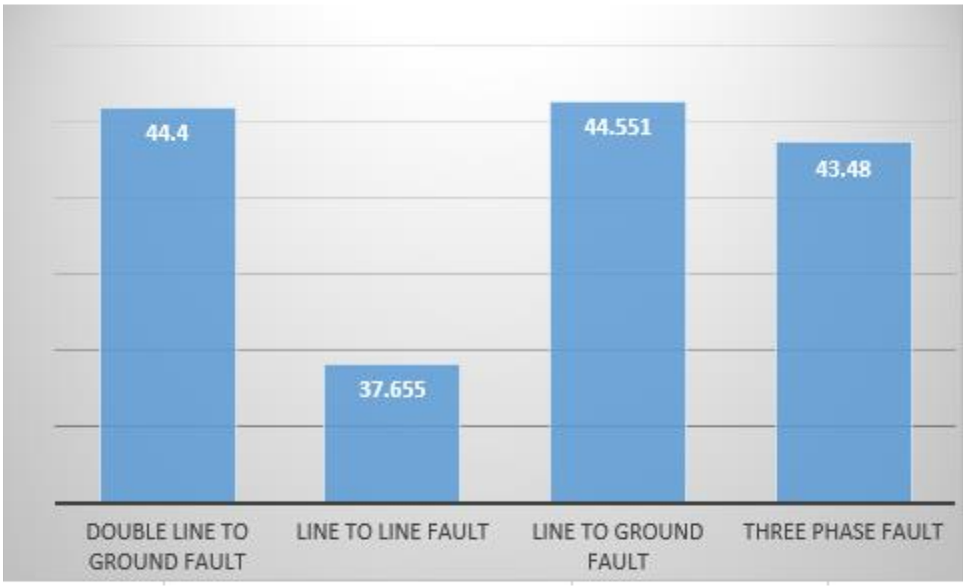

Figure 4.15: Comparison between different short circuit current at 11kv at parallel operation (2)

The highest value of I_k'' KA short circuit current in 11KVbusbar is a line to ground fault with a value of 44.551 KA

This Figure4.16 shows values of short circuit currents(I_k'' KA) at 33 KV bus bar at parallel(2) operation

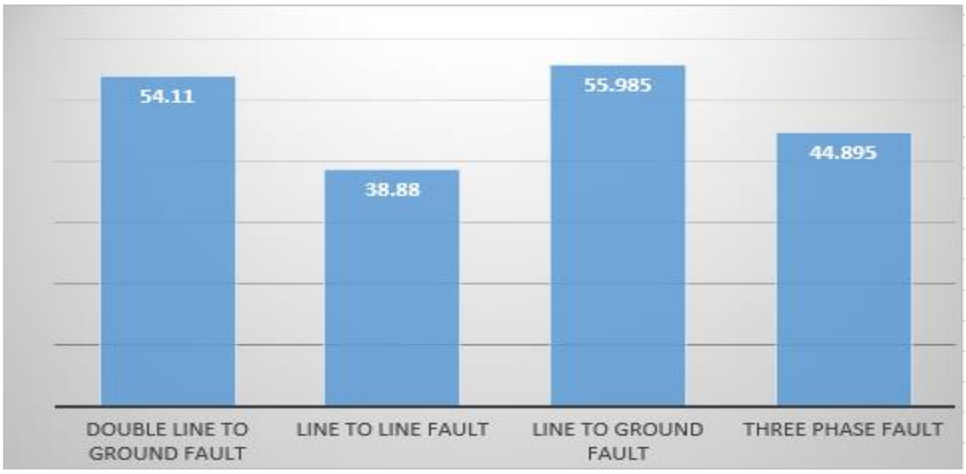

Figure 4.16: Comparison between different short circuit current at 33kv at parallel operation (2)

The highest value of I_k'' KA short circuit current in 33KVbusbar is a line to ground fault with a value of 55.985 KA

This Figure4.17 shows values of short circuit currents(I_k'' KA) at 110 KV bus bar at parallel(2) operation

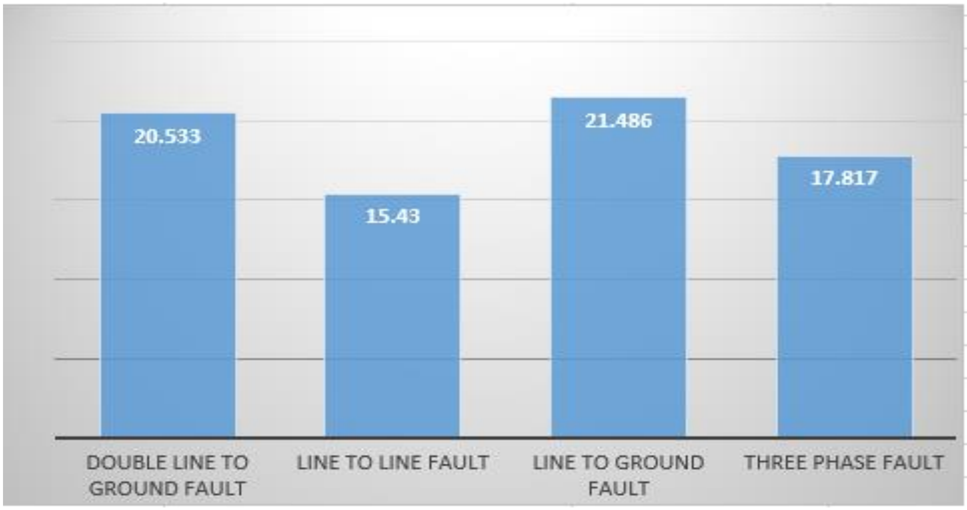

Figure 4.17: Comparison between different short circuit current at 110kv at parallel operation (2)

The highest value of I_k'' KA short circuit current in 11oKVbusbar is a line to ground fault with a value of 21.486 KA

This Figure4.18shows values of short circuit currents(I_k'' KA) at 0.415 KV bus bar at parallel(2) operation

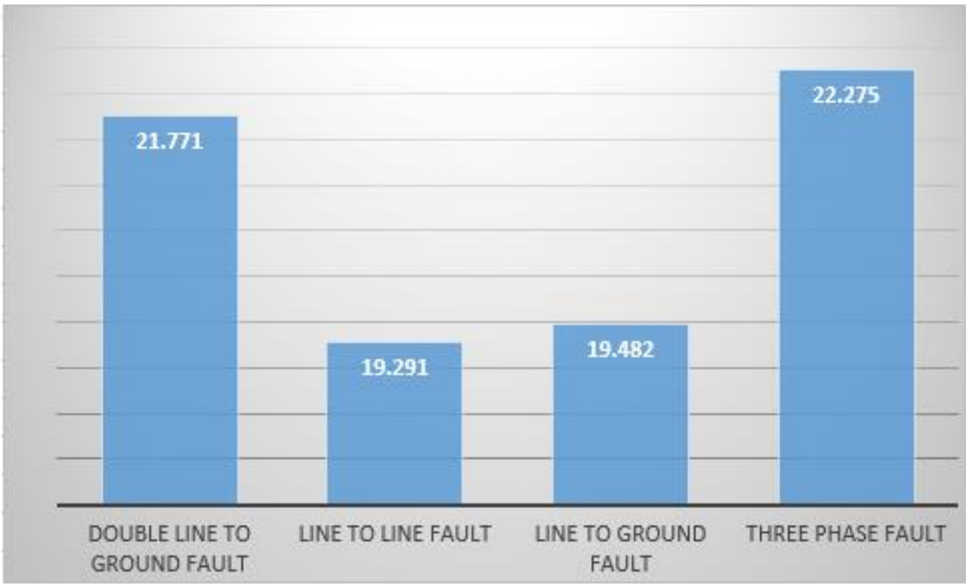

Figure 4.18: Comparison between different short circuit current at 0.415kv at parallel operation (2)

The highest value of I_k'' KA short circuit current in 0.415KV busbar is a three phase fault with a value of 22.275 KA.

Since design differ from any country to another depending on financial fund, philosophy and other factors. Design on worst case scenario requires high AC breaking capacity of circuit breaker and this is very costly. Circuit breakers ratings at different design depend on scenario of operation as shown inTable4.13

S.H Substation works always at normal operation so Breaker capacity is designed according to normal operation.

Parallel operation must be avoided because circuit breakers would damage if they were on the parallel operation during occur of fault.

Table 4.13 AC breaking capacity

Bus	Normal operation AC breaking capacity(KA)	Parallel(1) operation AC breaking capacity(KA)	Parallel(2) operation AC breaking capacity(KA)
At buses 11kv	25	50	50
At buses 33kv	31.5	63	63
At buses 110kv	12.5	25	25
At buses 0.415	25	25	25

Since power transformers tertiary is connected on delta, line to ground fault will not appear in this side (11 KV bus bar), a zigzag transformer was used

With 1:1 ratio. Zigzag transformer secondary is star connected. the star connection let ground fault calculated as shown in Figure 4.19

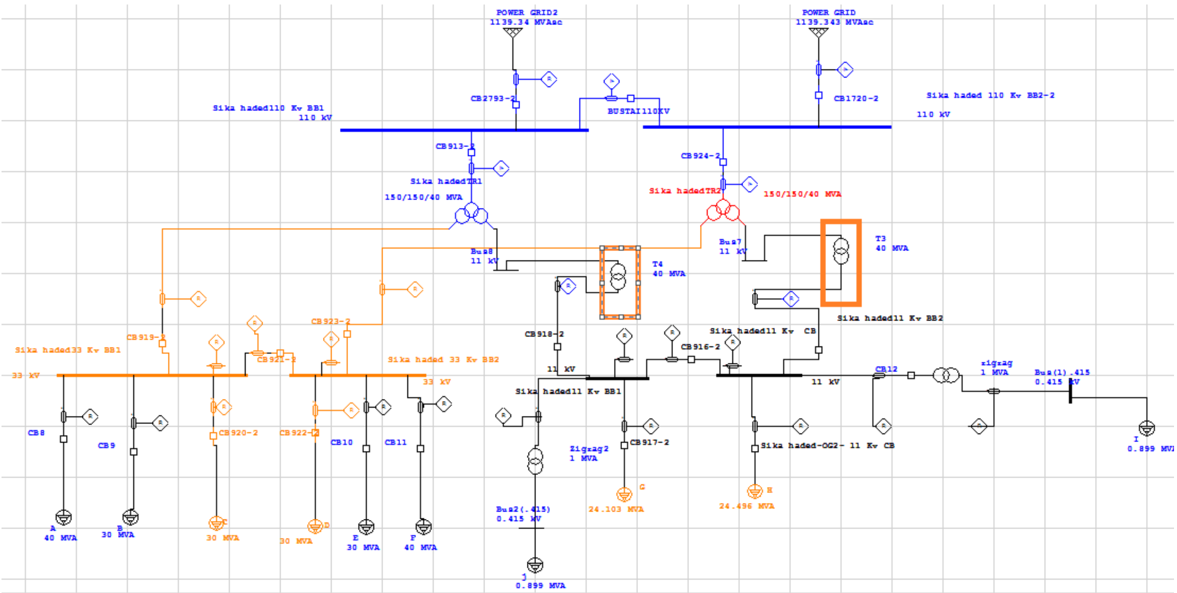

figure 4.19: Adding zigzag transformer to measure line to ground fault