POWER SYSTEM PROTECTION TERM PROJECT REPORT:

Introduction:

In this semester the term Project for our Course EE466-Power System Protection was about planning a defensive plan for a full power system. We are approached to plan a power system containing various parts like Power Grid (As a main source), Transformers, Induction Motors, Synchronous Motor, Circuit Breakers and Loads. The recently referenced parts were planned and associated by the accompanying boundaries:

Sr. No.	Component	Input Parameters
1	Power Grid U1 (Main Source)	3-Phase: MVAsc = 2000, X/R = 55
2	Transformer 1	3-Phase: 10 MVA, 115/13.8 kV, 7.5 %Z, Delta-Wye
3	Transformer 2	3-Phase: 20 MVA, 115/13.8 kV, 7.5 %Z, Delta-Wye
4	Transformer 3	3-Phase: 15 MVA, 115/13.8 kV, 6.5 %Z, Delta-Wye
5	Gen1 (Generator)	Subtransient Model, Round Rotor, Typical Data.
6	LUMP1 (Lump Load)	70% Motor Load & 30% Static Load, LRC = 650%, "High"; X/R=15; Use "Std MF" Option
7	Transformer 4	3-Phase: 5 MVA, 13.8/4.16 k, 6.5 %Z, Delta-Wye, -1.25%TapP
8	Transformer 5	3-Phase: 5 MVA, 13.8 kV/4.16, 7 %Z, Delta-Wye, -1.25%TapP
9	Syn1 (Synchronous Motor)	3-Phase: 2000 HP, Quantity = 2, 4 kV, 650%LRC
10	Cable1 (Cable)	Copper Cable, Length = 1500 ft, Z = 0.0223 + j0.0497 ohms/1000ft, T_{min} = 50, T_{max} = 75
11	Transformer 6	3-Phase: 2 MVA, 4.16/0.48 kV, 7 %Z, Delta-Delta, -2.50001%TapP
12	Mtr5 (Induction Motor)	Use "Std MF" Option
13	Mtr1 (Induction Motor)	Quantity = 4, Use "Std MF" Option
14	Load1 (Static Load)	2 MVA, 4.16 kV
15	Mtr2 (Induction Motor)	Quantity = 4, Use "Std MF" Option
16	Mtr3 (Induction Motor)	Quantity = 5, Use "Std MF" Option
17	Mtr4 (Induction Motor)	Use "Std MF" Option
18	Load2 (Static Load)	1 MVA, 0.48 kV

Protective Components:

Breaker Number	Type
CB1, CB3, CB4, CB5, CB6, CB7, CB8, CB9, CB10, CB11, CB12, CB13, CB14, CB15, CB16, CB17, CB18, CB19	High Voltage Circuit Breaker
CB20, CB21, CB22, CB23	Low Voltage Circuit Breaker

The report shows the plan of the protection plan on ETAP and how the Components are connected. It additionally shows the Protection type for each component and the type of relay along with the CT Ratio after the Proper Calculations.

The Report also contains screenshots of results which were obtained from ETAP i.e., "Load Flow Analysis" , "Short Circuit Analysis" , and the "Sequence of Relay Operation For Tripping a Specific Circuit Breaker".

We are asked to show all the results for TWO Configurations.

In First Configuration CB-1 is closed-tie.

Whereas, in Second Configuration CB-1 is open.

Procedure:

We are asked to design Protection Scheme of Given Power System for TWO Configurations:

- **Closed Tie CB-1 (Normal Configuration)**
- **CB-1 (Open)**

Let's start with 1st Configuration.

1- Closed tie CB-1 (Normal Configuration):

We began the Circuit in ETAP by adding every of the parts which is mentioned above to the ETAP "Edit Mode" and connected them to obtain the Required Diagram. We entered the details of each component as needed by the recently referenced Table. Thus, We obtain Full Circuit Diagram as Shown in Figure 1.

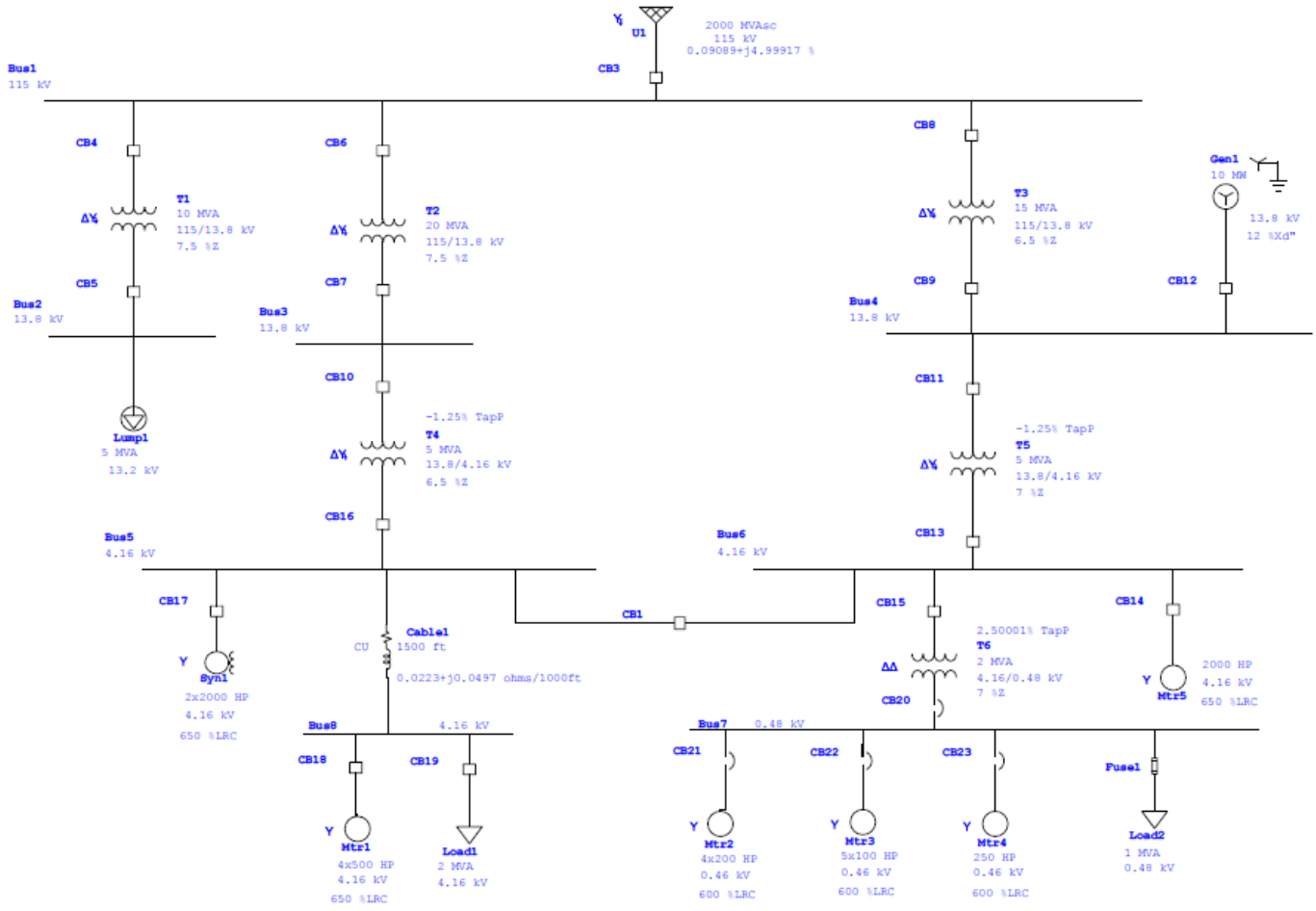

Fig. 1 Power System Diagram (Close-tie Configuration)

For Protecting our components we have to set Relays. For setting Relays we need to configure Current Transformer (CT). For CT we need CT Ratio as an Input Value for CT. For Turn Ratio of CT we need Maximum Load Current Flowing through each component. So, To get this data Firstly we did a Load Flow Analysis of this Power System. It brought about showing the current and the power of each branch in the diagram. These outcomes are appeared in Figure 2.

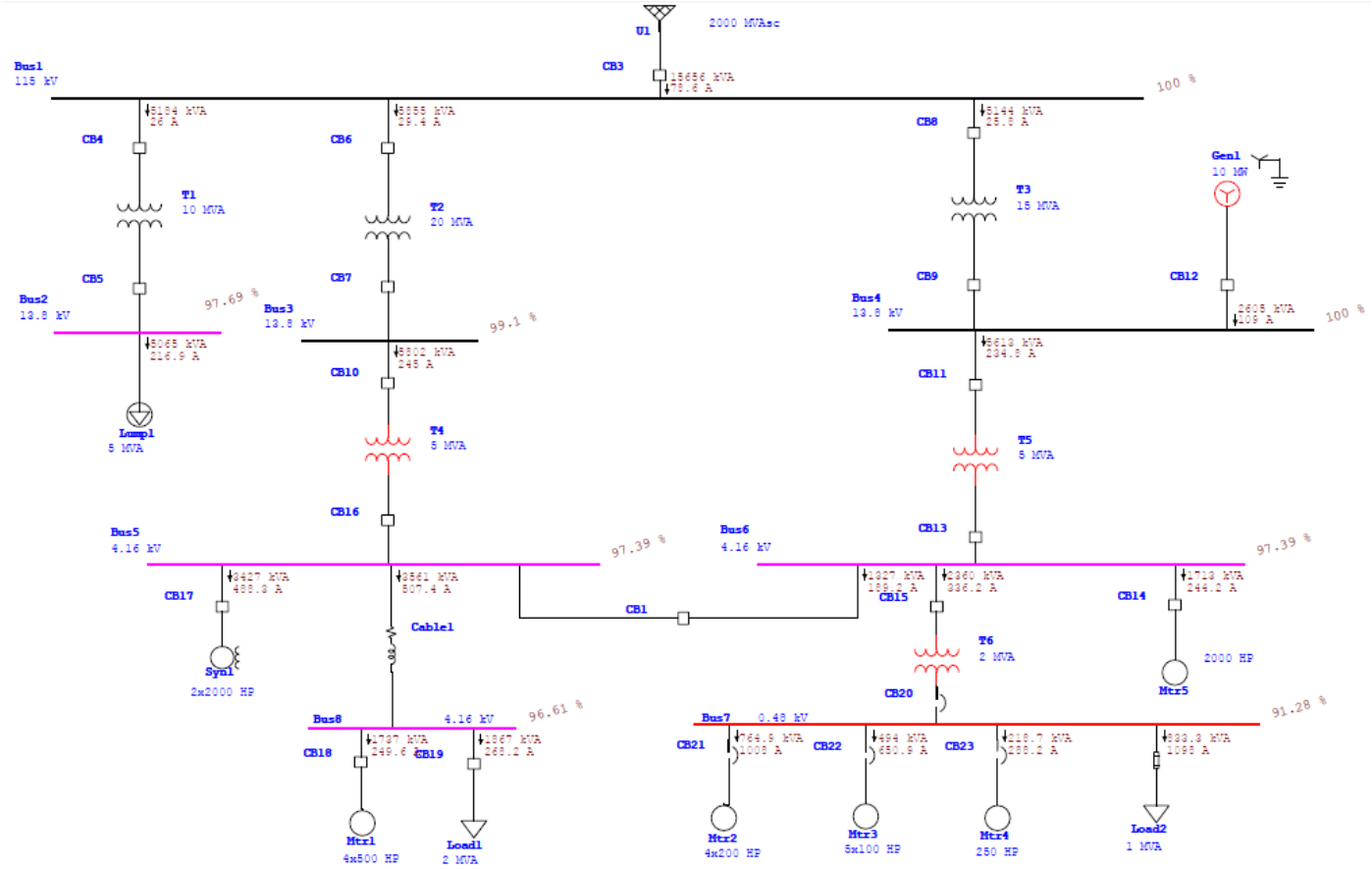

Fig. 2 Power System Diagram After Running Load Flow Analysis (Close-tie Configuration)

Conclusion Obtained From Load Flow Analysis,

Component	*Maximum Load Current (A)*	*Apparent Power (kVA)*
U1 Power Grid	*78.6*	*15656*
Transformer 1	*26*	*5184*
Transformer 2	*29.4*	*5855*
Transformer 3	*25.8*	*5144*
Transformer 4	*245*	*5802*
Transformer 5	*234.8*	*5613*
Transformer 6	*336.2*	*2360*
Lump1	*216.9*	*5065*
Gen1	*109*	*2605*
Syn1	*488.3*	*3427*

Cable1	*507.4*	*2561*
Motor1	*249.6*	*1737*
Motor2	*1008*	*764.9*
Motor3	*650.9*	*494*
Motor4	*288.2*	*218.7*
Motor5	*244.2*	*1713*
Load1	*268.2*	*1867*
Load2	*1098*	*833.3*

Table 1 Load Flow Results (Close-tie Configuration)

For Turn Ratio of CT we also need the Fault Current Flowing through each component. So, to get fault currents we did a Short Circuit Analysis of this Power System. It brought about showing the Fault Current of each branch in the diagram. These outcomes are appeared in Figure 3.

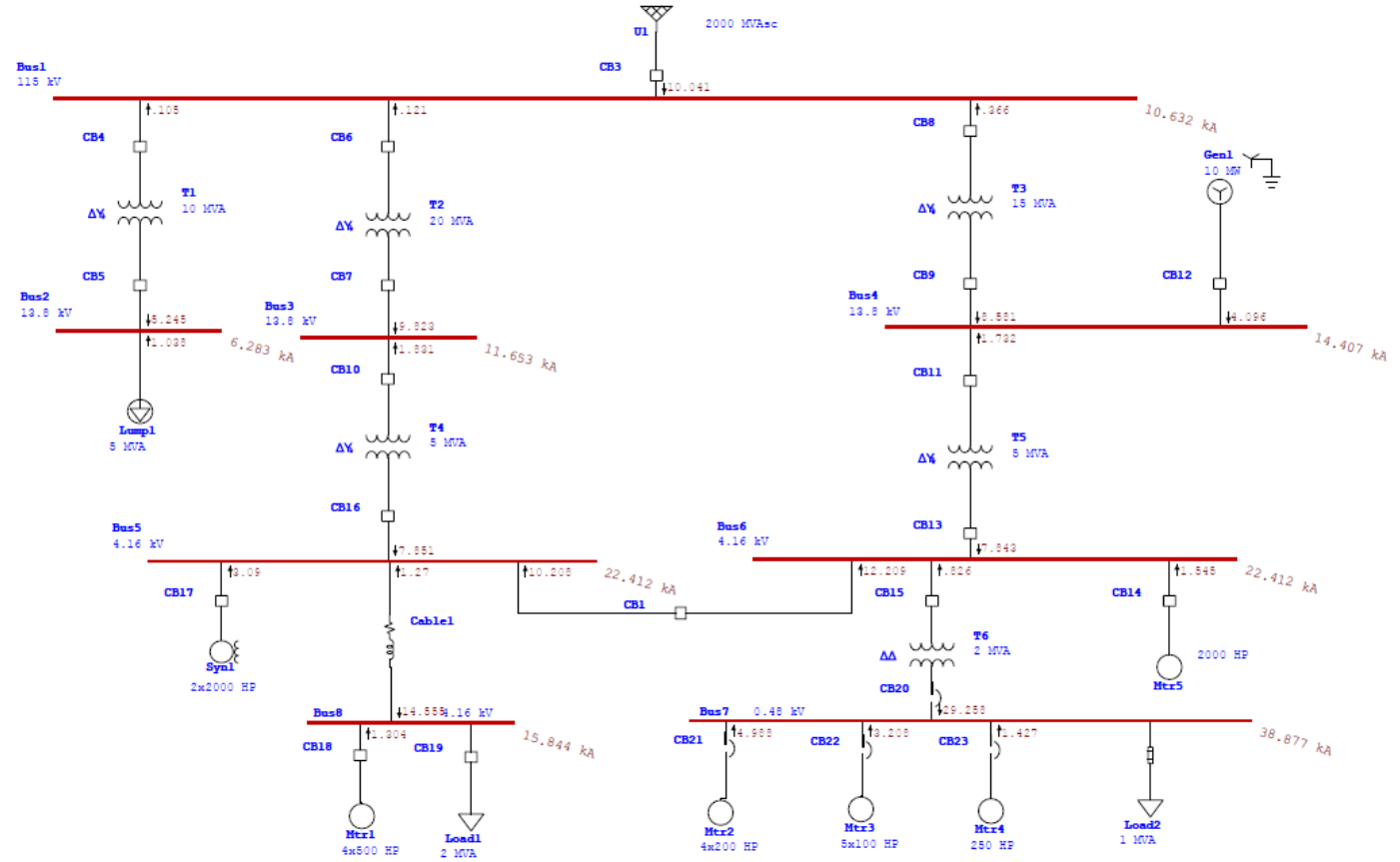

Fig. 3 Power System Diagram After Running Short Circuit Analysis (Close-tie Configuration)

Now we need to choose the CT ratios and relays properly to trip the circuit Breaker Properly. Below Table shows the Standard CT Ratios.

Then we have to choose nearest CT Ratio from the Below Table.

Sr. No.	Manufacturer's Maximum Production	Standard Values
1	600:5	50:5, 100:5, 150:5, 200:5, 250:5, 300:5, 400:5, 450:5, 500:5, 600:5
2	1200:5	100:5, 200:5, 300:5, 400:5, 500:5, 600:5, 800:5, 900:5, 1000:5, 1200:5
3	2000:5	300:5, 400:5, 500:5, 800:5, 1100:5, 1200:5, 1500:5, 1600:5, 2000:5
4	3000:5	300:5, 500:5, 800:5, 1000:5, 1200:5, 1500:5, 2000:5, 2200:5, 2500:5, 3000:5
5	4000:5	500:5, 1000:5, 1500:5, 2000:5, 2500:5, 3000:5, 3500:5, 4000:5
6	5000:5	500:5, 1000:5, 1500:5, 2000:5, 2500:5, 3000:5, 3500:5, 4000:5, 5000:5

Table 2 Standard CT Values

With the reference from Table of Standard CT Values and Maximum Load Current $\mathbf{I_{MAX\text{-}LOAD}}$ (which we get after Load Flow Analysis). To increase the relay's Protection Capability, we will always choose values that are closer to the $\mathbf{I_{MAX\text{-}LOAD}}$.

Sr. No.	Component	$\mathbf{I_{MAX\text{-}LOAD}}$ **(A)**	CT Ratio
1	Power Grid	78.6	100:5
2	Transformer 1 (Primary Side)	26	50:5
3	Transformer 1 (Secondary Side)	216.9	250:5
4	Transformer 2 (Primary Side)	29.4	50:5
5	Transformer 2 (Secondary Side)	245	250:5
6	Transformer 3 (Primary Side)	25.8	50:5
7	Transformer 3 (Secondary Side)	234.8	250:5
8	Transformer 4 (Primary Side)	245	250:5
9	Transformer 4 (Secondary Side)	1184.9	1200:5
10	Transformer 5 (Primary Side)	234.8	250:5
11	Transformer 5 (Secondary Side)	769.6	800:5
12	Transformer 6 (Primary Side)	336.2	400:5
13	Transformer 6 (Secondary Side)	3045.1	3500:5
14	Gen1(Generator)	109	150:5
15	Syn1 (Synchronous Motor)	488.3	500:5
16	Mtr1 (Induction Motor)	249.6	300:5
17	Mtr2 (Induction Motor)	1008	1100:5
18	Mtr3 (Induction Motor)	650.9	800:5
19	Mtr4 (Induction Motor)	288.2	300:5
20	Mtr5 (Induction Motor)	244.2	250:5
21	Load1 (Static Load)	268.2	300:5

Table 3 Selected CT Values

After Adding the Current Transformers (CT's), Over-Current Relays & Differential Relays (For Differential Protection of Transformers) the Power System Diagram Looks:

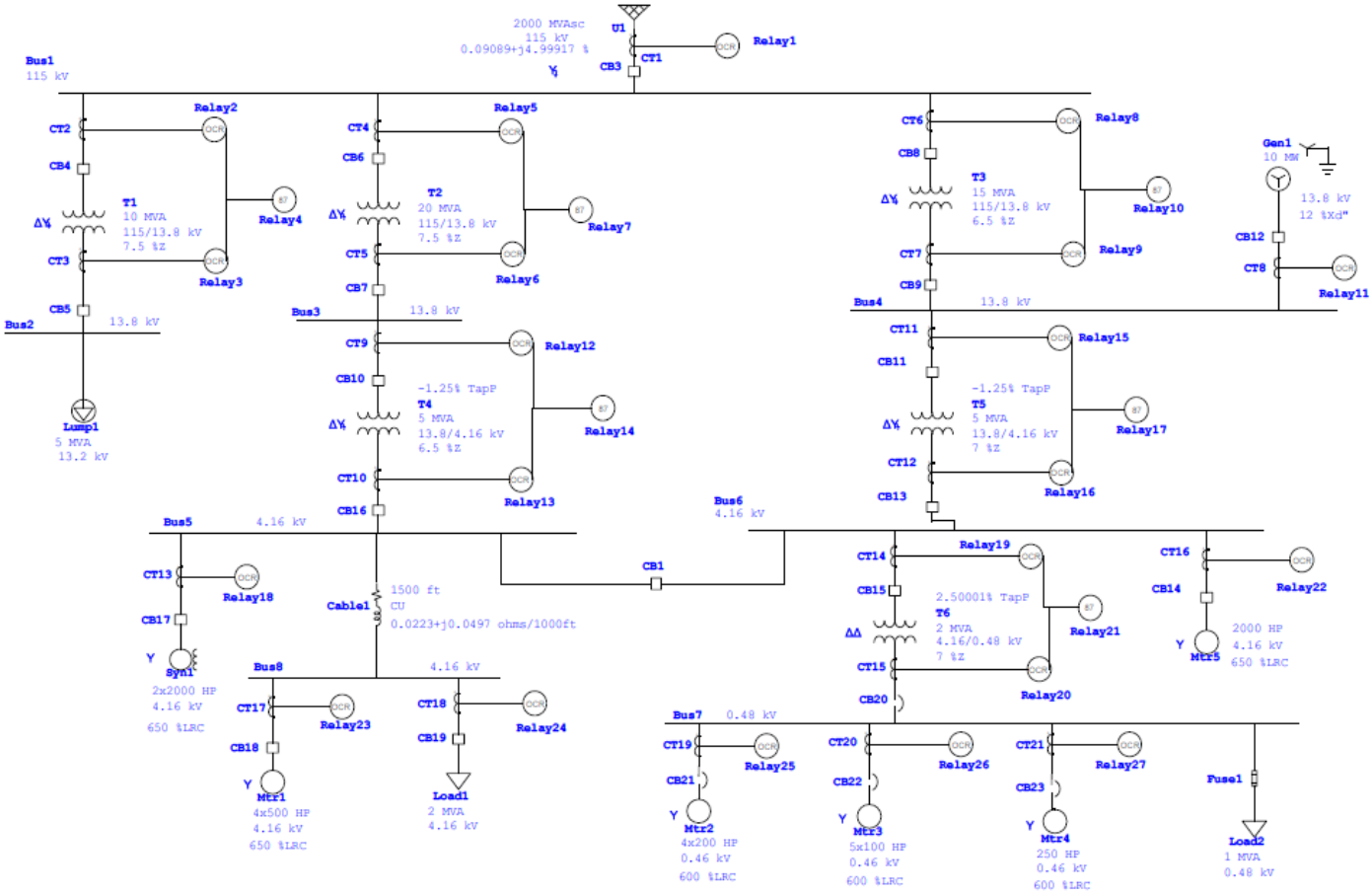

Fig. 4 Power System Diagram After adding CT's & Relays (Close-tie Configuration)

Now it's time to select Relay Model from ETAP Library & to Calculate I_{Pickup} For Each Component, From I_{Pickup} we get Pickup Value.

To calculate I_{pickup} we use the following relation,

$$\mathbf{2 \times I_{Max\text{-}Load} < I_{Pickup} < 1/3 \times I_{Max\text{-}Fault}}$$

<u>For Power Grid U1 (Main Source):</u>

As I_{Pickup},

$$2 \times I_{Max\text{-}Load} < I_{Pickup}$$

$$2 \times 78.6 < I_{Pickup}$$

$$157.2 < I_{Pickup}$$

For T1 (High Voltage Side):

$$2 \times 26 < I_{Pickup}$$

$$52 < I_{Pickup}$$

For T1 (Low Voltage Side):

$$2 \times 216.9 < I_{Pickup}$$

$$433.8 < I_{Pickup}$$

For T2 (High Voltage Side):

$$2 \times 29.4 < I_{Pickup}$$

$$58.8 < I_{Pickup}$$

For T2 (Low Voltage Side):

$$2 \times 245 < I_{Pickup}$$

$$490 < I_{Pickup}$$

For T3 (High Voltage Side):

$$2 \times 25.8 < I_{Pickup}$$

$$51.6 < I_{Pickup}$$

For T3 (Low Voltage Side):

$$2 \times 234.8 < I_{Pickup}$$

$$469.6 < I_{Pickup}$$

For T4 (High Voltage Side):

$$2 \times 245 < I_{Pickup}$$

$$490 < I_{Pickup}$$

For T4 (Low Voltage Side):

$$2 \times 1184.9 < I_{Pickup}$$

$$2369.8 < I_{Pickup}$$

For T5 (High Voltage Side):

$$2 \times 234.8 < I_{Pickup}$$

$$469.6 < I_{Pickup}$$

For T5 (Low Voltage Side):

$$2 \times 769.6 < I_{Pickup}$$

$$1539.2 < I_{Pickup}$$

For T6 (High Voltage Side):

$$2 \times 336.2 < I_{Pickup}$$

$$672.4 < I_{Pickup}$$

For T6 (Low Voltage Side):

$$2 \times 3045.1 < I_{Pickup}$$

$$6090.2 < I_{Pickup}$$

For Gen1:

$$2 \times 109 < I_{Pickup}$$

$$218 < I_{Pickup}$$

For Syn1:

$$2 \times 488.3 < I_{Pickup}$$

$$976.6 < I_{Pickup}$$

For Mtr1:

$$2 \times 249.6 < I_{Pickup}$$

$$499.2 < I_{Pickup}$$

For Mtr2:

$$2 \times 1008 < I_{Pickup}$$

$$2016 < I_{Pickup}$$

For Mtr3:

$$2 \times 650.9 < I_{Pickup}$$

$$1301.8 < I_{Pickup}$$

For Mtr4:

$$2 \times 288.2 < I_{Pickup}$$

$$576.4 < I_{Pickup}$$

For Mtr5:

$$2 \times 244.2 < I_{Pickup}$$

$$488.4 < I_{Pickup}$$

For Load1:

$$2 \times 268.2 < I_{Pickup}$$

$$536.4 < I_{Pickup}$$

In ETAP, if we enter Pickup value in relay settings then it automatically I_{Pickup}. So, we randomly entered some values for Pickup to get Desired I_{Pickup} for every component. By this Process we got Pickup value for Every Component. So, we make following Table. The specifications of relays also showed in Table 4.

Sr. No.	Component	Relay ID	Relay Model	Protection Type	I_{Pickup}	Pickup value	Relay Output
1	Power Grid	Relay1	ABB 50D	Time delay over current	157.2<	8	Open CB3
2	Transformer 1 (Primary Side)	Relay2	ABB 50D	Time delay over current	52<	5.3	Open CB4
3	Transformer 1 (Secondary Side)	Relay3	ABB 50D	Time delay over current	433.8<	8.7	Open CB5
4	Transformer 1	Relay4	ABB HU	Differential	-	-	Open CB4-CB5
5	Transformer 2 (Primary Side)	Relay5	ABB 50D	Time delay over current	58.8<	5.9	Open CB6
6	Transformer 2 (Secondary Side)	Relay6	ABB 50D		490<	9.9	Open CB7
7	Transformer 2	Relay7	ABB HU	Differential	-	-	Open CB6-CB7
8	Transformer 3 (Primary Side)	Relay8	ABB 50D	Time delay over current	51.6<	5.2	Open CB8
9	Transformer 3 (Secondary Side)	Relay9	ABB 50D	Time delay over current	469.6<	9.4	Open CB9
10	Transformer 3	Relay10	ABB HU	Differential	-	-	Open CB8-CB9
11	Transformer 4 (Primary Side)	Relay12	ABB 50D	Time delay over current	490<	9.9	Open CB10
12	Transformer 4 (Secondary Side)	Relay13	ABB 50D	Time delay over current	2369.8<	9.9	Open CB16
	Transformer 4	Relay14	ABB HU	Differential	-	-	Open CB10-CB16
13	Transformer 5 (Primary Side)	Relay15	ABB 50D	Time delay over current	469.6<	9.4	Open CB11
14	Transformer 5 (Secondary Side)	Relay16	ABB 50D	Time delay over current	1539.2<	19.3	Open CB13
15	Transformer 5	Relay17	ABB HU	Differential	-	-	Open CB11-CB13
16	Transformer 6 (Primary Side)	Relay19	ABB 50D	Time delay over current	672.4<	8.5	Open CB15
17	Transformer 6 (Secondary Side)	Relay20	ABB 50D	Time delay over current	6090.2<	8.71	Open CB20
18	Transformer 6	Relay21	ABB HU	Differential	-	-	Open CB15-CB20
19	Syn1 (Synchronous Motor)	Relay18	GE Multilin IAC-66M	Time delay over current	976.6<	9.8	Open CB17
20	Mtr1 (Induction Motor)	Relay23	GE Multilin IAC-66M	Time delay over current	499.2<	10,9	Open CB18

21	Mtr2 (Induction Motor)	Relay25	GE Multilin IAC-66M	Time delay over current	2016<	10	Open CB21
22	Mtr3 (Induction Motor)	Relay26	GE Multilin IAC-66M	Time delay over current	1301.8<	10	Open CB22
23	Mtr4 (Induction Motor)	Relay27	GE Multilin IAC-66M	Time delay over current	576.4<	10	Open CB23
24	Mtr5 (Induction Motor)	Relay22	GE Multilin IAC-66M	Time delay over current	488.4<	10	Open CB14
25	Load1 (Static Load)	Relay24	GE Multilin IAC-66M	Time delay over current	536.4<	9	Open CB19
26	Gen1 (Generator)	Relay 11	GE Multilin 489		218<	1.5	Open CB12

Table 4 Relay Specifications for each component

Now, it's time to check our protection scheme. Go, to star Protection & Coordination system. Run 3-Phase Symmetrical fault on every Bus one by one and check the tripping operation of Circuit breakers.

FAULT AT BUS 1:

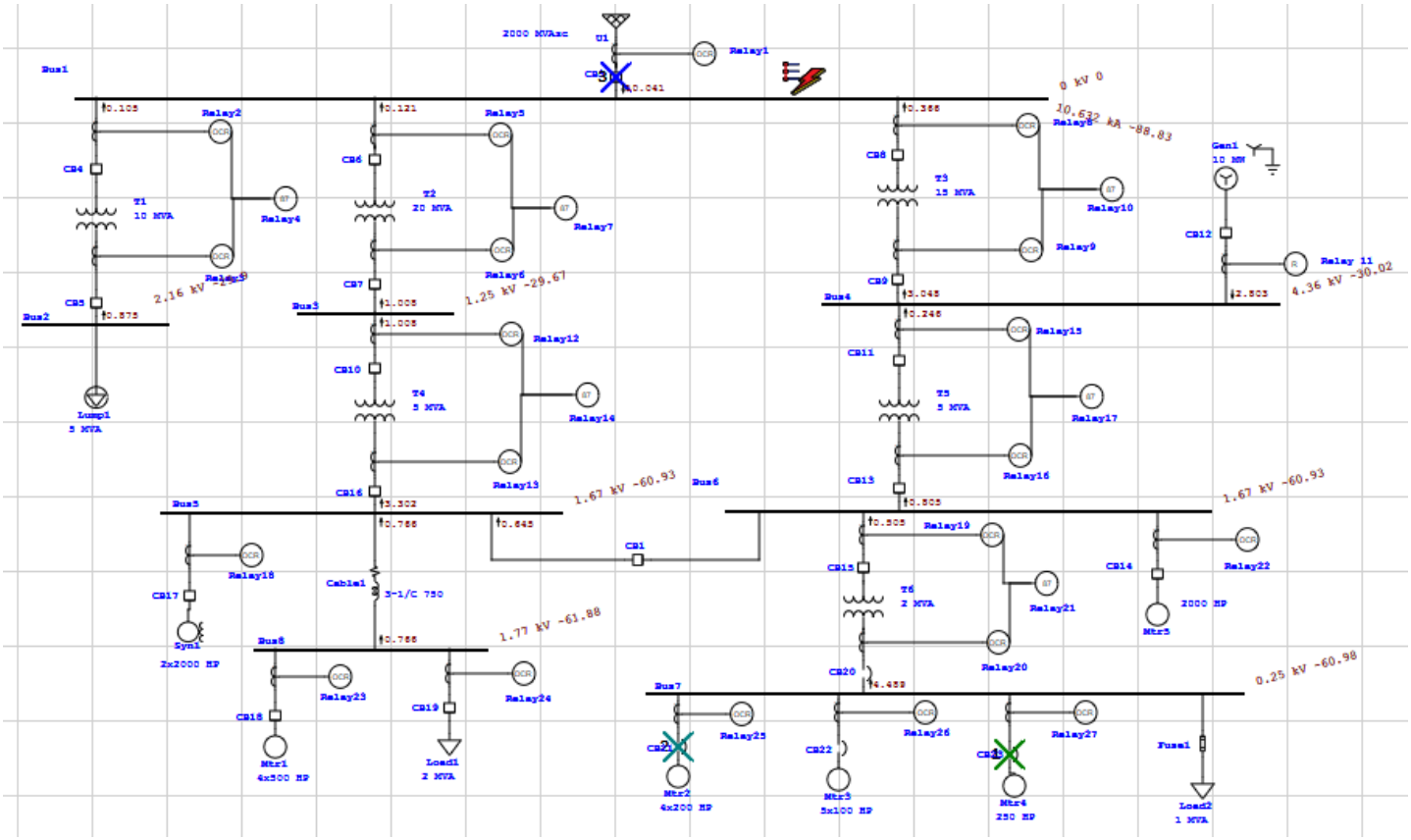

Fig. 5 Fault at Bus 1(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus1

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	10.041	10.0		Phase - OC1 - 50
10.0	Relay2	0.105	10.0		Phase - OC1 - 50
10.0	Relay3	0.875	10.0		Phase - OC1 - 50
10.0	Relay5	0.121	10.0		Phase - OC1 - 50
10.0	Relay6	1.008	10.0		Phase - OC1 - 50
10.0	Relay8	0.366	10.0		Phase - OC1 - 50
10.0	Relay9	3.048	10.0		Phase - OC1 - 50
10.0	Relay12	1.008	10.0		Phase - OC1 - 50
10.0	Relay13	3.302	10.0		Phase - OC1 - 50
10.0	Relay 11	2.803	10.0		Phase - OC1 - 50
14.8	Relay22	0.945	9.0	14.8	Phase - OC1 - 50
19.0	Relay23	0.766	13.6	19.0	Phase - OC1 - 50
23.7	Relay27	0.666	19.0	23.7	Phase - OC1 - 50
24.8	Relay25	2.327	20.3	24.8	Phase - OC1 - 50
73.7	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
74.8	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB4		83.3		Tripped by Relay2 Phase - OC1 - 50
93.3	CB5		83.3		Tripped by Relay3 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
98.2	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
102	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
2782	Relay 11	2.803	2782		Overload Phase - Thermal
2866	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal
4109	Relay 11	2.803	4109		Phase - OC1 - 51
4192	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 6 Relay Sequence of Operation

FAULT AT BUS 2:

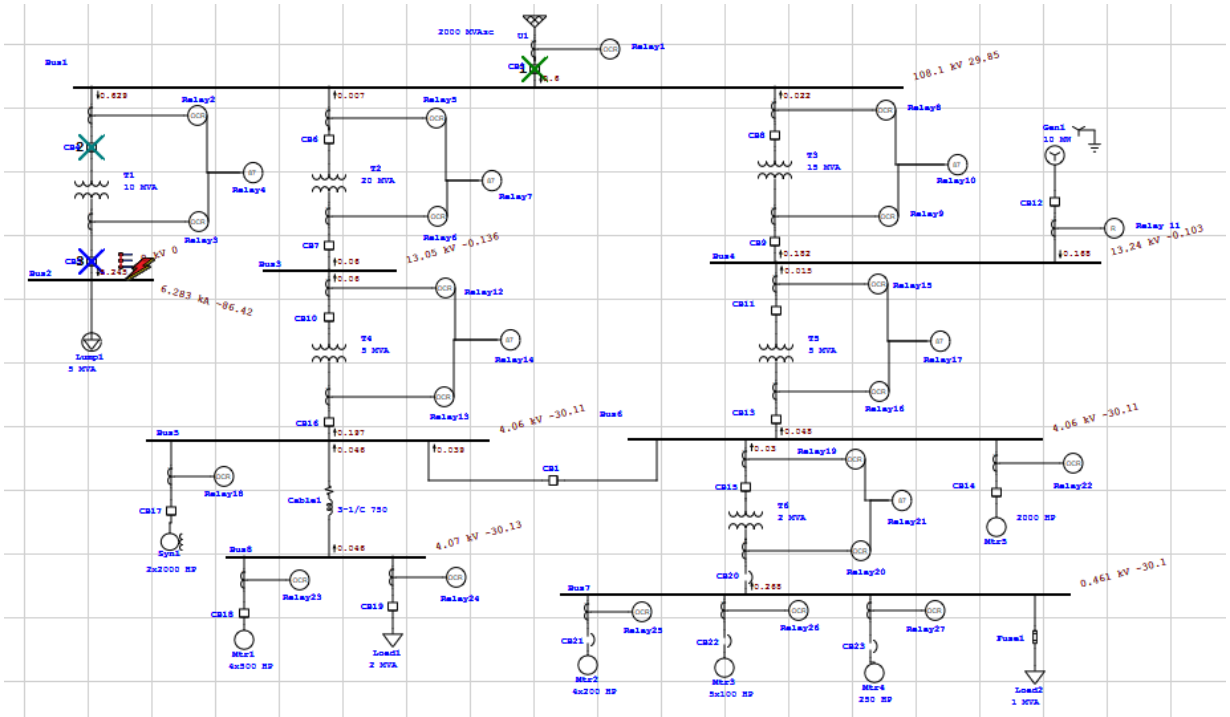

Fig. 7 Fault at Bus 2(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus2

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.6	10.0		Phase - OC1 - 50
10.0	Relay2	0.629	10.0		Phase - OC1 - 50
10.0	Relay3	5.245	10.0		Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB4		83.3		Tripped by Relay2 Phase - OC1 - 50
93.3	CB5		83.3		Tripped by Relay3 Phase - OC1 - 50

Fig. 8 Relay Sequence of Operation

FAULT AT BUS 3:

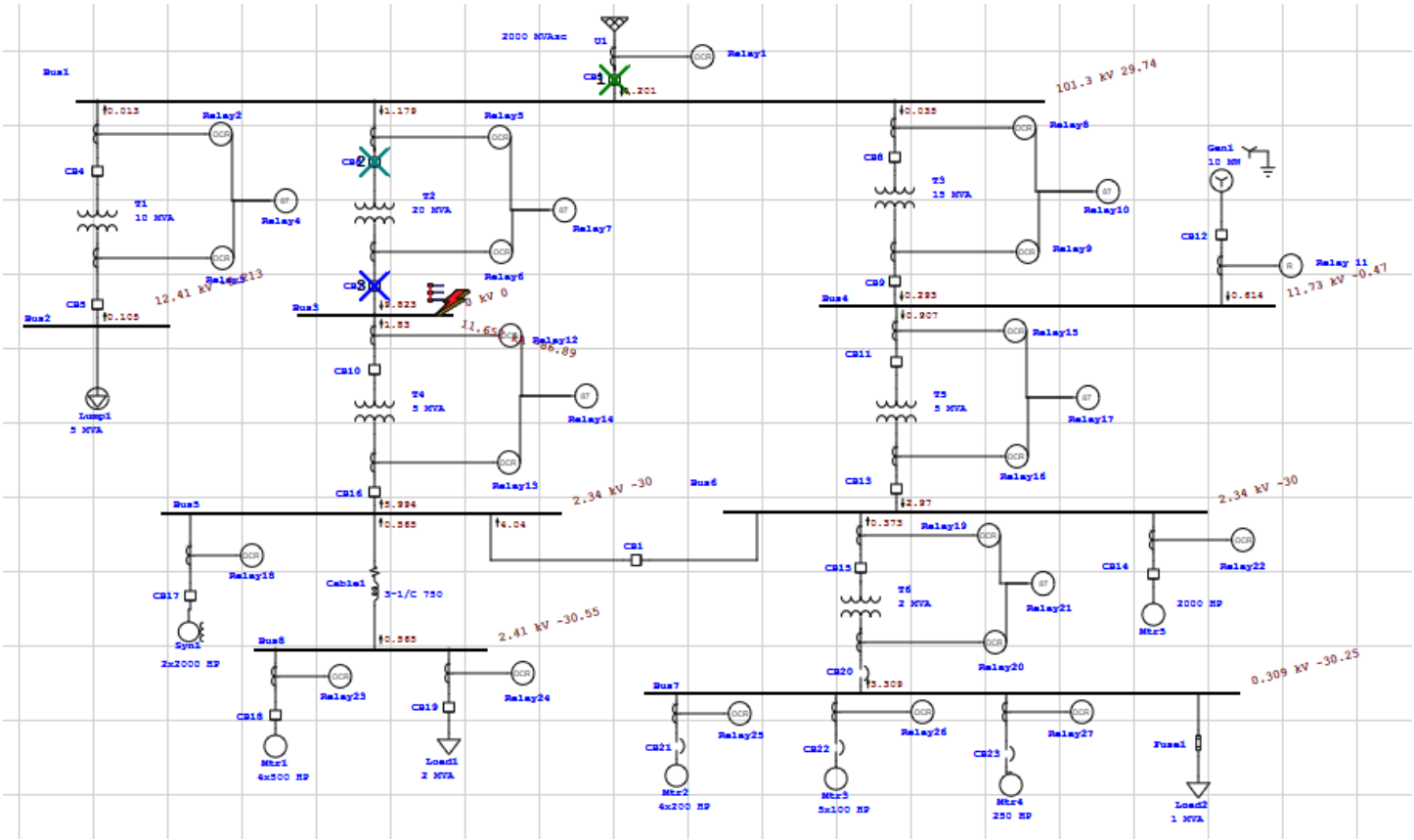

Fig. 9 Fault at Bus 3(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus3

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	1.201	10.0		Phase - OC1 - 50
10.0	Relay5	1.179	10.0		Phase - OC1 - 50
10.0	Relay6	9.823	10.0		Phase - OC1 - 50
10.0	Relay12	1.83	10.0		Phase - OC1 - 50
10.0	Relay13	5.994	10.0		Phase - OC1 - 50
10.0	Relay15	0.907	10.0		Phase - OC1 - 50
10.0	Relay16	2.97	10.0		Phase - OC1 - 50
10.0	Relay 11	0.614	10.0		Phase - OC1 - 50
19.3	Relay22	0.697	13.9	19.3	Phase - OC1 - 50
25.0	Relay23	0.565	20.6	25.0	Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
103	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
108	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
41496	Relay 11	0.614	41496		Phase - OC1 - 51
41579	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51
157246	Relay 11	0.614	157246		Overload Phase - Thermal
157329	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal

Fig. 10 Relay Sequence of Operation

FAULT AT BUS 4:

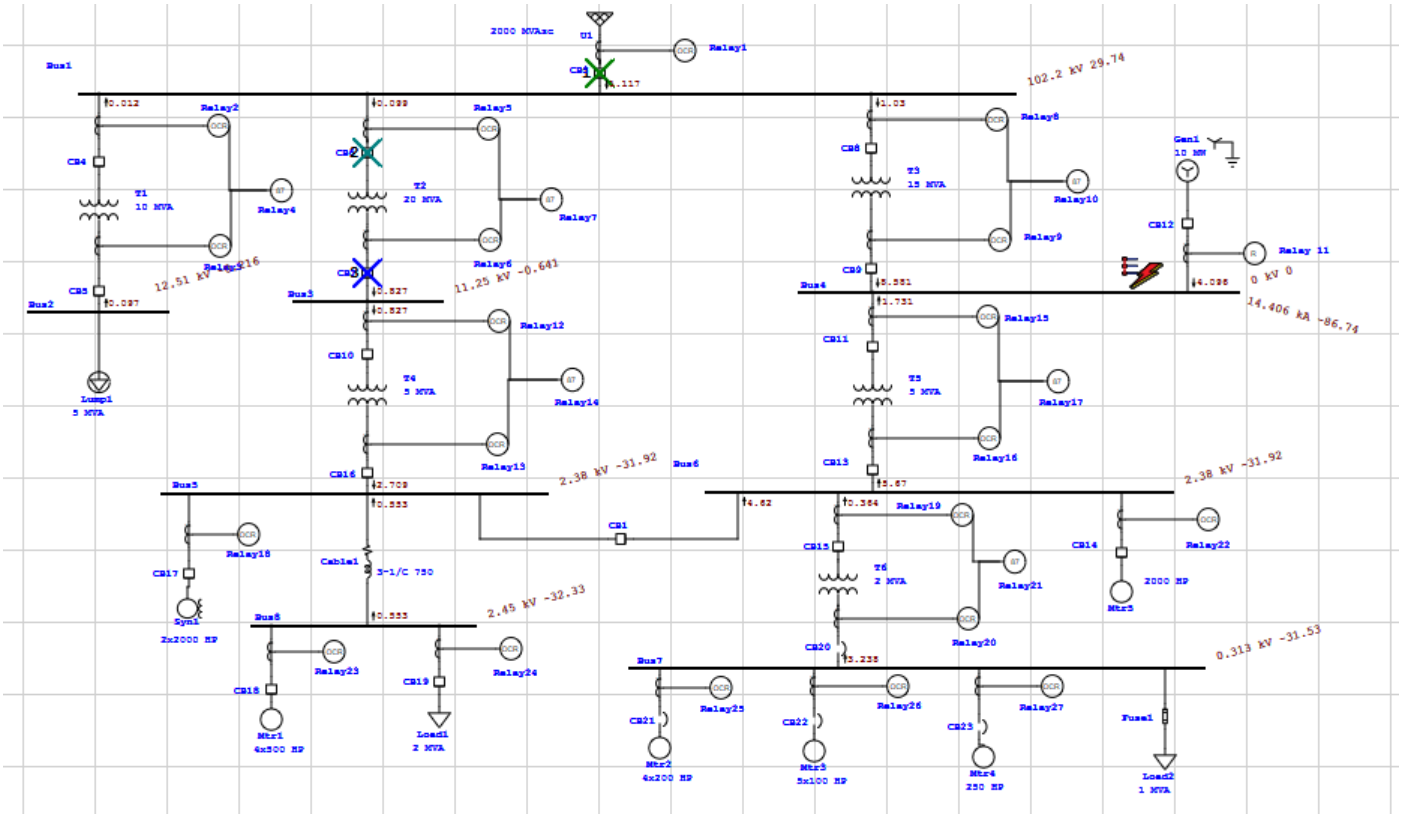

Fig. 11 Fault at Bus 4(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus4

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	1.117	10.0		Phase - OC1 - 50
10.0	Relay5	0.099	10.0		Phase - OC1 - 50
10.0	Relay6	0.827	10.0		Phase - OC1 - 50
10.0	Relay8	1.03	10.0		Phase - OC1 - 50
10.0	Relay9	8.581	10.0		Phase - OC1 - 50
10.0	Relay12	0.827	10.0		Phase - OC1 - 50
10.0	Relay13	2.709	10.0		Phase - OC1 - 50
10.0	Relay15	1.731	10.0		Phase - OC1 - 50
10.0	Relay16	5.67	10.0		Phase - OC1 - 50
10.0	Relay 11	4.096	10.0		Phase - OC1 - 50
19.7	Relay22	0.682	14.4	19.7	Phase - OC1 - 50
25.5	Relay23	0.553	21.3	25.5	Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
103	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
109	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
1388	Relay 11	4.096	1388		Overload Phase - Thermal
1471	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal
3192	Relay 11	4.096	3192		Phase - OC1 - 51
3275	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 12 Relay Sequence of Operation

FAULT AT BUS 5:

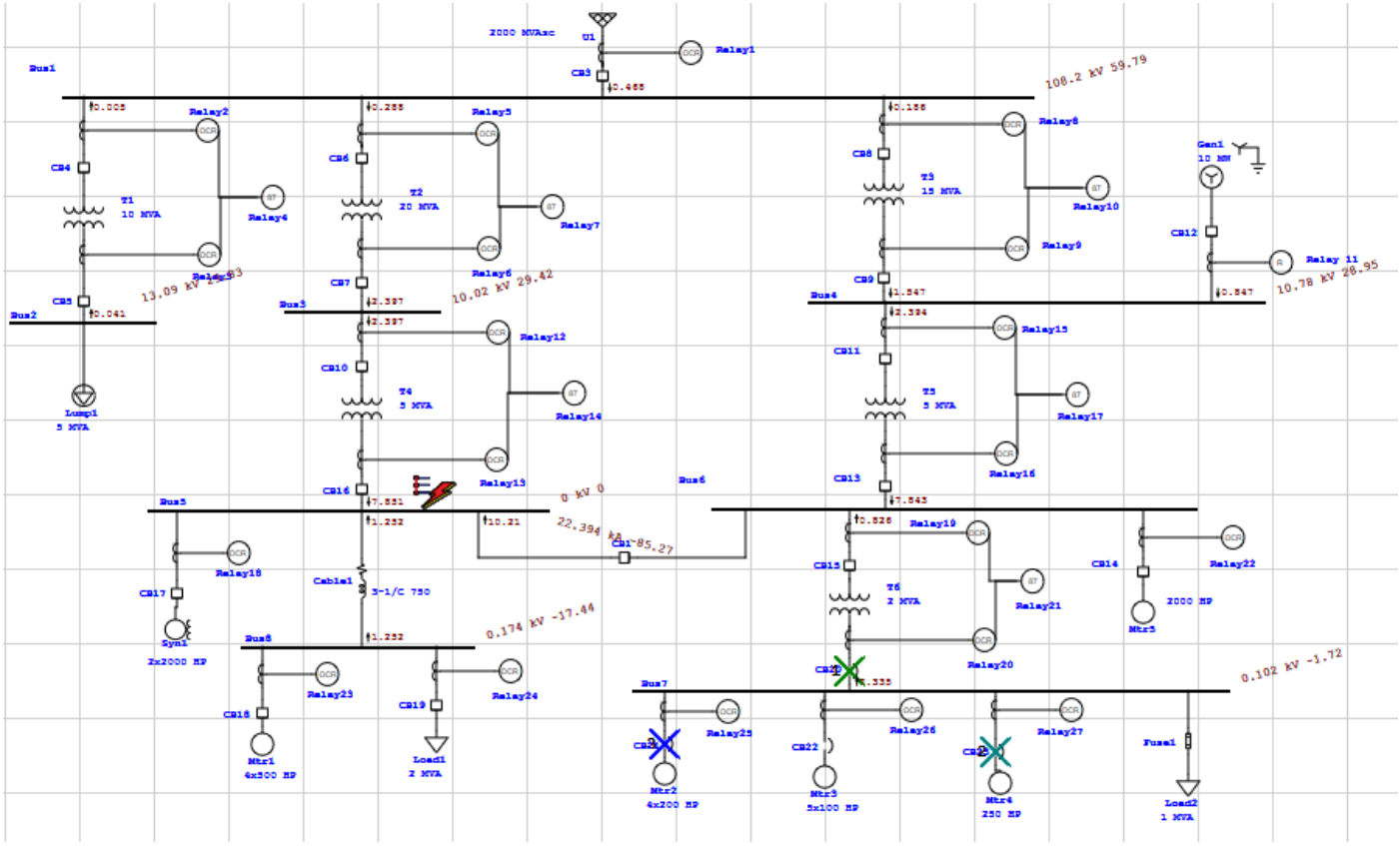

Fig. 13 Fault at Bus 5(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus5

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.468	10.0		Phase - OC1 - 50
10.0	Relay5	0.288	10.0		Phase - OC1 - 50
10.0	Relay6	2.397	10.0		Phase - OC1 - 50
10.0	Relay8	0.186	10.0		Phase - OC1 - 50
10.0	Relay9	1.547	10.0		Phase - OC1 - 50
10.0	Relay12	2.397	10.0		Phase - OC1 - 50
10.0	Relay13	7.851	10.0		Phase - OC1 - 50
10.0	Relay15	2.394	10.0		Phase - OC1 - 50
10.0	Relay16	7.843	10.0		Phase - OC1 - 50
10.0	Relay19	0.826	10.0		Phase - OC1 - 50
10.0	Relay20	7.335	10.0		Phase - OC1 - 50
10.0	Relay 11	0.847	10.0		Phase - OC1 - 50
10.3	Relay22	1.545	3.8	10.3	Phase - OC1 - 50
12.7	Relay23	1.252	6.4	12.7	Phase - OC1 - 50
15.3	Relay27	1.088	9.7	15.3	Phase - OC1 - 50
15.9	Relay25	3.803	10.4	15.9	Phase - OC1 - 50
17.8	Relay26	2.446	12.3	17.8	Phase - OC1 - 50
60.0	CB20		50.0		Tripped by Relay20 Phase - OC1 - 50
65.3	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
65.9	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
67.8	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB15		83.3		Tripped by Relay19 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
93.6	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
96.0	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
21067	Relay 11	0.847	21067		Phase - OC1 - 51
21150	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51
44560	Relay 11	0.847	44560		Overload Phase - Thermal
44643	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal

Fig. 14 Relay Sequence of Operation

FAULT AT BUS 6:

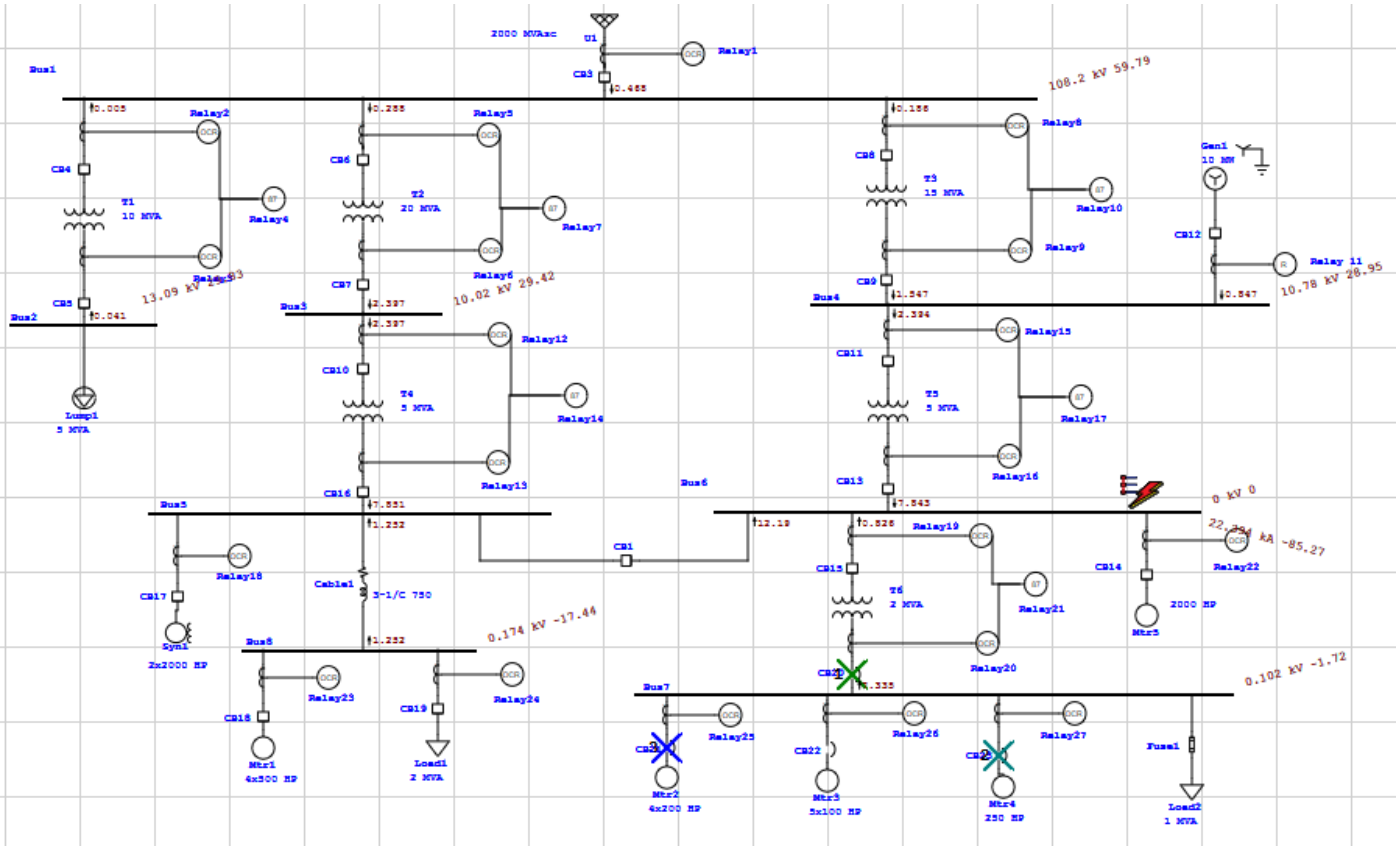

Fig. 15 Fault at Bus 6(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus6

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.468	10.0		Phase - OC1 - 50
10.0	Relay5	0.288	10.0		Phase - OC1 - 50
10.0	Relay6	2.397	10.0		Phase - OC1 - 50
10.0	Relay8	0.186	10.0		Phase - OC1 - 50
10.0	Relay9	1.547	10.0		Phase - OC1 - 50
10.0	Relay12	2.397	10.0		Phase - OC1 - 50
10.0	Relay13	7.851	10.0		Phase - OC1 - 50
10.0	Relay15	2.394	10.0		Phase - OC1 - 50
10.0	Relay16	7.843	10.0		Phase - OC1 - 50
10.0	Relay19	0.826	10.0		Phase - OC1 - 50
10.0	Relay20	7.335	10.0		Phase - OC1 - 50
10.0	Relay 11	0.847	10.0		Phase - OC1 - 50
10.3	Relay22	1.545	3.8	10.3	Phase - OC1 - 50
12.7	Relay23	1.252	6.4	12.7	Phase - OC1 - 50
15.3	Relay27	1.088	9.7	15.3	Phase - OC1 - 50
15.9	Relay25	3.803	10.4	15.9	Phase - OC1 - 50
17.8	Relay26	2.446	12.3	17.8	Phase - OC1 - 50
60.0	CB20		50.0		Tripped by Relay20 Phase - OC1 - 50
65.3	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
65.9	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
67.8	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50

93.3	CB6	83.3	Tripped by Relay5 Phase - OC1 - 50
93.3	CB7	83.3	Tripped by Relay6 Phase - OC1 - 50
93.3	CB8	83.3	Tripped by Relay8 Phase - OC1 - 50
93.3	CB9	83.3	Tripped by Relay9 Phase - OC1 - 50
93.3	CB10	83.3	Tripped by Relay12 Phase - OC1 - 50
93.3	CB11	83.3	Tripped by Relay15 Phase - OC1 - 50
93.3	CB12	83.3	Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13	83.3	Tripped by Relay16 Phase - OC1 - 50
93.3	CB15	83.3	Tripped by Relay19 Phase - OC1 - 50
93.3	CB16	83.3	Tripped by Relay13 Phase - OC1 - 50
93.6	CB16	83.3	Tripped by Relay22 Phase - OC1 - 50
96.0	CB18	83.3	Tripped by Relay23 Phase - OC1 - 50

21067	Relay 11	0.847	21067	Phase - OC1 - 51
21150	CB12		83.3	Tripped by Relay 11 Phase - OC1 - 51
44560	Relay 11	0.847	44560	Overload Phase - Thermal
44643	CB12		83.3	Tripped by Relay 11 Overload Phase - Thermal

Fig. 16 Relay Sequence of Operation

FAULT AT BUS 7:

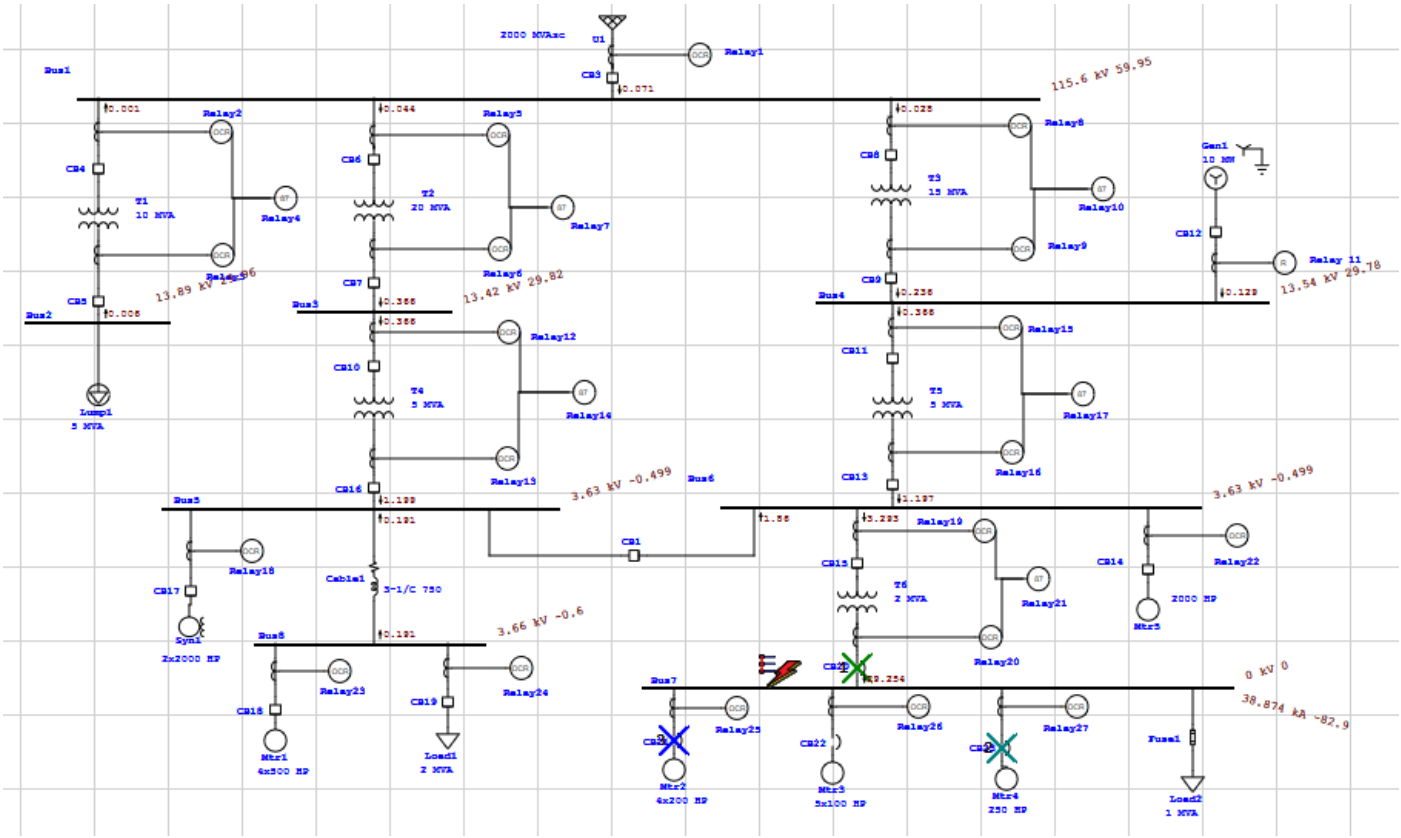

Fig. 17 Fault at Bus 7(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus7

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay19	3.293	10.0		Phase - OC1 - 50
10.0	Relay20	29.254	10.0		Phase - OC1 - 50
12.5	Relay27	1.427	6.1	12.5	Phase - OC1 - 50
12.9	Relay25	4.988	6.6	12.9	Phase - OC1 - 50
14.2	Relay26	3.208	8.2	14.2	Phase - OC1 - 50
60.0	CB20		50.0		Tripped by Relay20 Phase - OC1 - 50
62.5	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
62.9	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
64.2	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB15		83.3		Tripped by Relay19 Phase - OC1 - 50

Fig. 18 Relay Sequence of Operation

FAULT AT BUS 8:

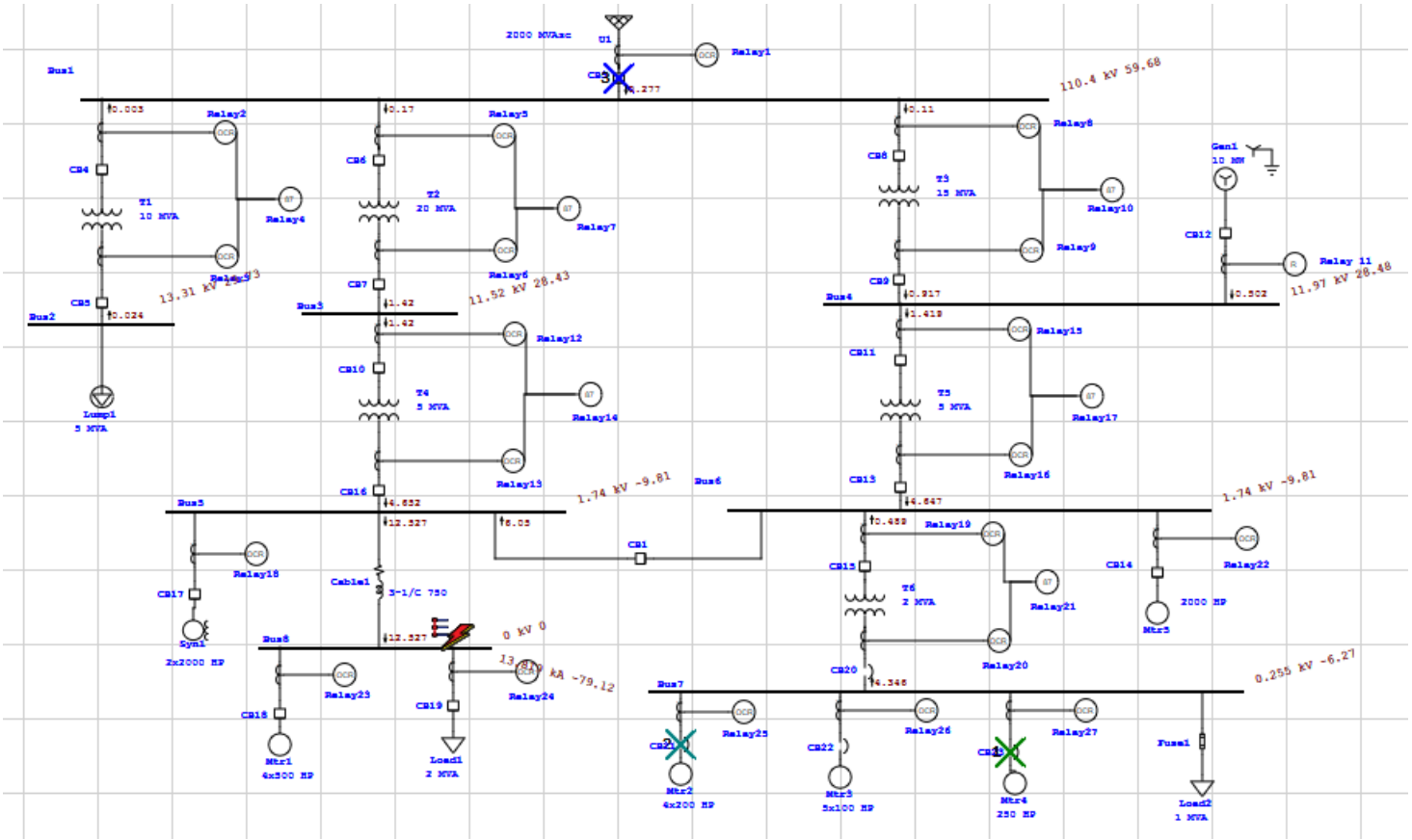

Fig. 19 Fault at Bus 8(Closed tie configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus8

Data Rev.: Base Config: Normal Date: 04-14-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.277	10.0		Phase - OC1 - 50
10.0	Relay5	0.17	10.0		Phase - OC1 - 50
10.0	Relay6	1.42	10.0		Phase - OC1 - 50
10.0	Relay8	0.11	10.0		Phase - OC1 - 50
10.0	Relay9	0.917	10.0		Phase - OC1 - 50
10.0	Relay12	1.42	10.0		Phase - OC1 - 50
10.0	Relay13	4.652	10.0		Phase - OC1 - 50
10.0	Relay15	1.419	10.0		Phase - OC1 - 50
10.0	Relay16	4.647	10.0		Phase - OC1 - 50
10.0	Relay 11	0.502	10.0		Phase - OC1 - 50
12.3	Relay23	1.304	5.9	12.3	Phase - OC1 - 50
15.2	Relay22	0.915	9.5	15.2	Phase - OC1 - 50
24.4	Relay27	0.645	19.9	24.4	Phase - OC1 - 50
25.5	Relay25	2.253	21.2	25.5	Phase - OC1 - 50
74.4	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
75.5	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
95.6	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
98.5	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
67094	Relay 11	0.502	67094		Phase - OC1 - 51
67177	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51
2165942	Relay 11	0.502	2165942		Overload Phase - Thermal
2166025	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal

Fig. 20 Relay Sequence of Operation

2- CB-1 (Open):

Now in this step we change the state of Circuit Breaker (CB-1) from close to open. As shown in Figure Below.

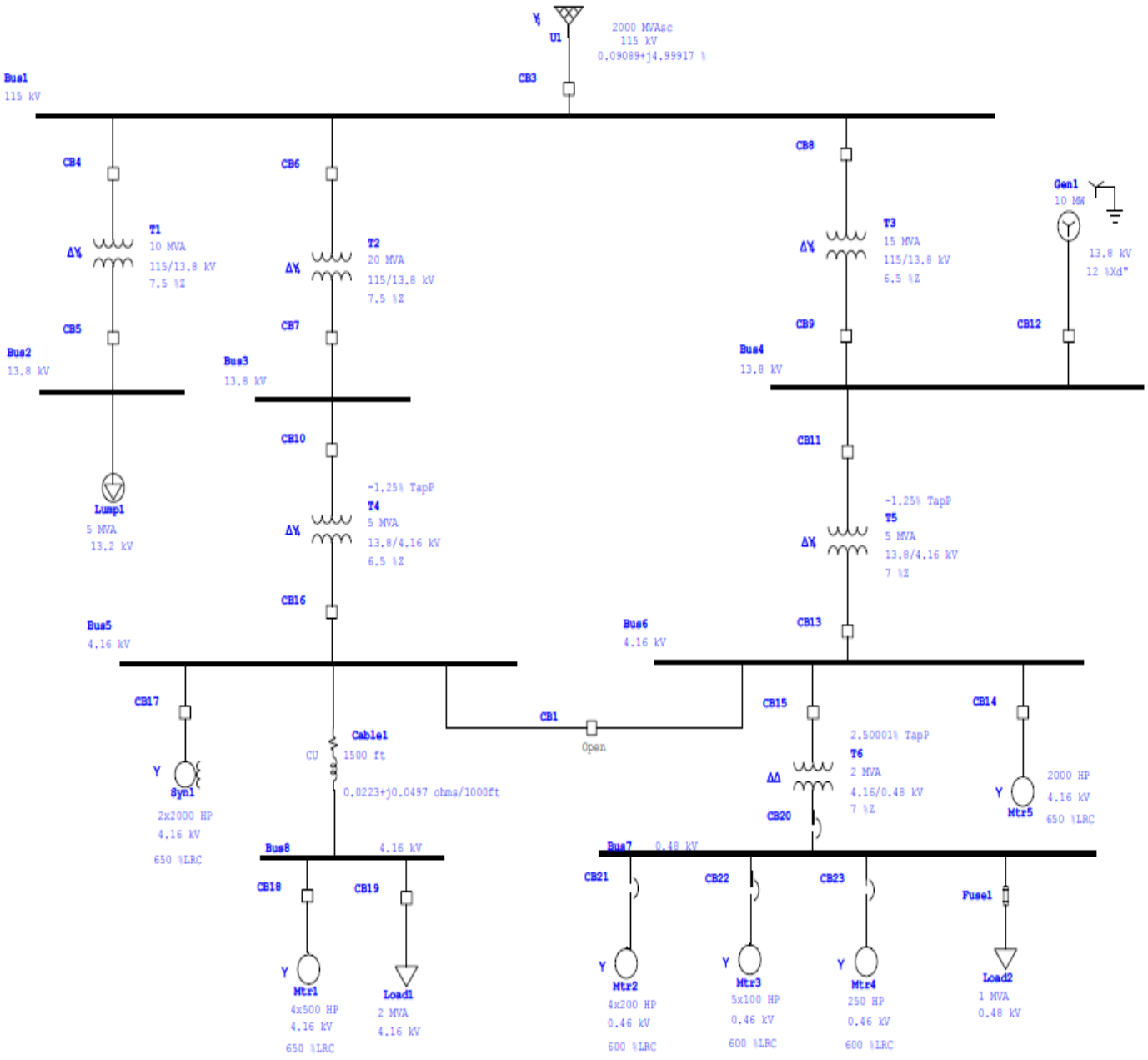

Fig. 21 Power System Diagram (CB-1 Open Configuration)

Again we repeat load flow analysis for CB-1 Open Configuration to obtain Maximum Load Current by which we can easily find CT Ratios for every component.

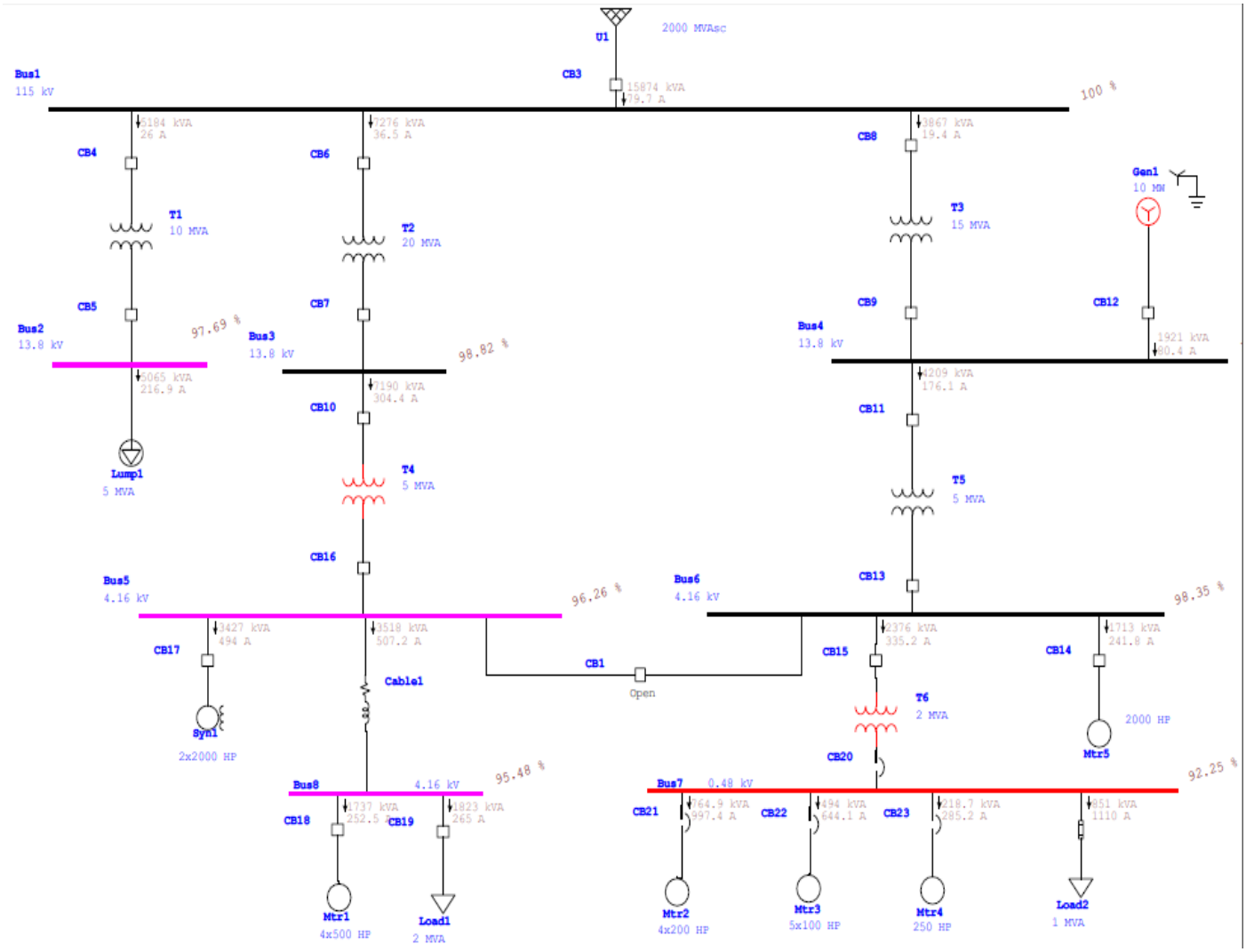

Fig. 22 Power System Diagram After Running Load Flow Analysis (CB-1 Open Configuration)

Conclusion Obtained From Load Flow Analysis,

Component	*Maximum Load Current (A)*	*Apparent Power (kVA)*
U1 Power Grid	*79.7*	*15874*
Transformer 1	*26*	*5184*
Transformer 2	*36.5*	*7276*
Transformer 3	*19.4*	*3867*
Transformer 4	*304.4*	*7190*
Transformer 5	*176.1*	*4209*
Transformer 6	*335.2*	*2376*
Lump1	*216.9*	*5065*
Gen1	*80.4*	*1921*
Syn1	*494*	*3427*
Cable1	*507.2*	*3518*

Motor1	*252.5*	*1737*
Motor2	*997.4*	*764.9*
Motor3	*644.1*	*494*
Motor4	*285.2*	*218.7*
Motor5	*241.8*	*1713*
Load1	*265*	*1823*
Load2	*1110*	*851*

Table 4 Load Flow Results (CB-1 Open Configuration)

For Turn Ratio of CT we also need the Fault Current Flowing through each component. So, to get fault currents we did a Short Circuit Analysis of this Power System. It brought about showing the Fault Current of each branch in the diagram. These outcomes are appeared in Figure 23.

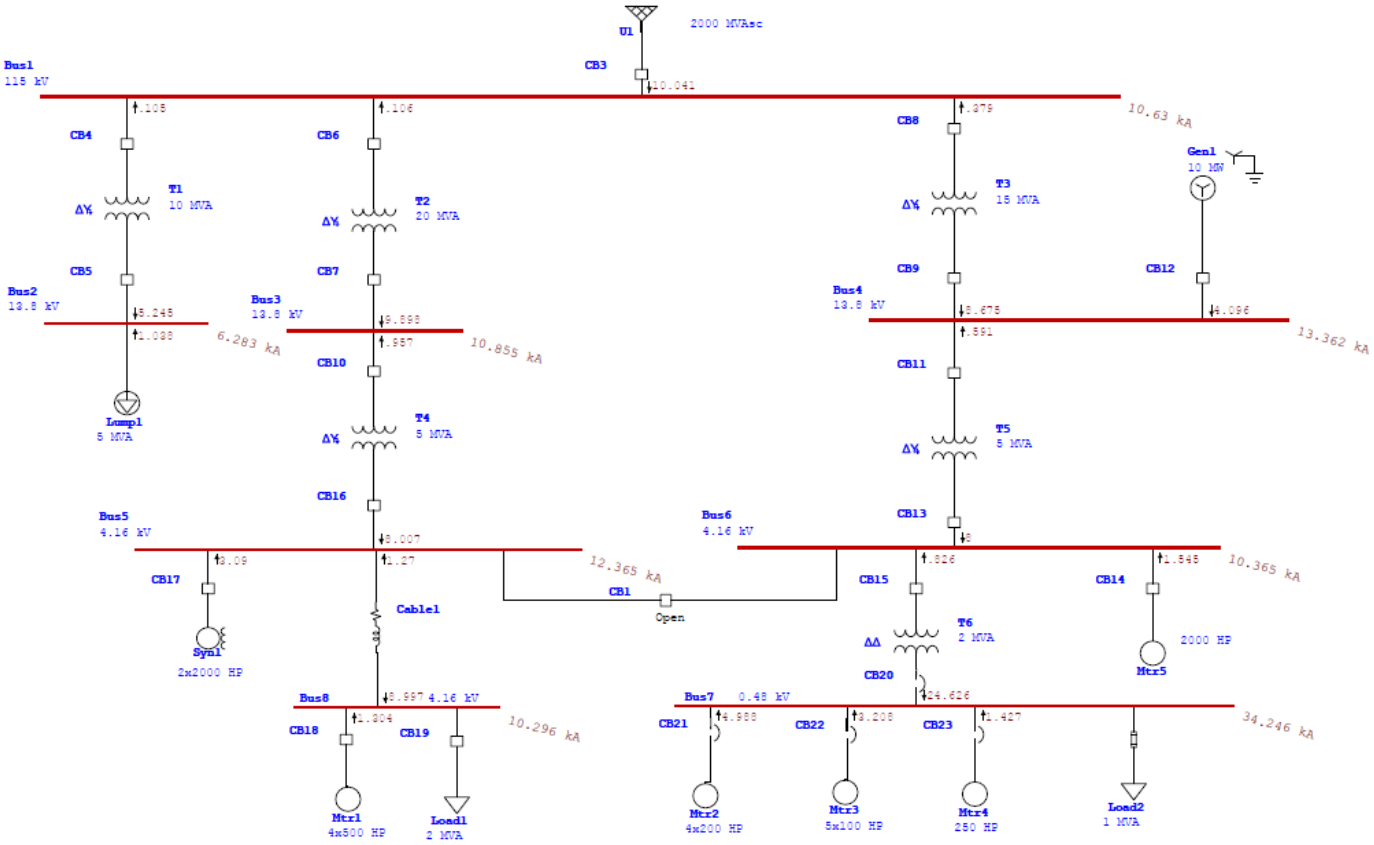

Fig. 23 Power System Diagram After Running Short Circuit Analysis (CB-1 Open Configuration)

Now we need to choose the CT ratios and relays properly to trip the circuit Breaker Properly. With the reference from Table of Standard CT Values and Maximum Load Current $\mathbf{I_{MAX\text{-}LOAD}}$ (which we get after Load Flow Analysis). To increase the relay's Protection Capability, we will always choose values that are closer to the $\mathbf{I_{MAX\text{-}LOAD}}$.

Sr. No.	Component	$I_{MAX\text{-}LOAD}$ (A)	CT Ratio
1	Power Grid	79.7	100:5
2	Transformer 1 (Primary Side)	26	50:5
3	Transformer 1 (Secondary Side)	216.9	250:5
4	Transformer 2 (Primary Side)	36.5	50:5
5	Transformer 2 (Secondary Side)	304.4	400:5
6	Transformer 3 (Primary Side)	19.4	50:5
7	Transformer 3 (Secondary Side)	176.1	200:5
8	Transformer 4 (Primary Side)	304.4	400:5
9	Transformer 4 (Secondary Side)	1001.2	1100:5
10	Transformer 5 (Primary Side)	176.1	200:5
11	Transformer 5 (Secondary Side)	577	600:5
12	Transformer 6 (Primary Side)	335.2	400:5
13	Transformer 6 (Secondary Side)	3036.7	3500:5
14	Gen1(Generator)	80.4	100:5
15	Syn1 (Synchronous Motor)	494	500:5
16	Mtr1 (Induction Motor)	252.5	300:5
17	Mtr2 (Induction Motor)	997.4	1000:5
18	Mtr3 (Induction Motor)	644.1	800:5
19	Mtr4 (Induction Motor)	285.2	300:5
20	Mtr5 (Induction Motor)	241.8	250:5
21	Load1 (Static Load)	265	300:5

Table 6 Selected CT Values

After Adding the Current Transformers (CT's), Over-Current Relays & Differential Relays (For Differential Protection of Transformers) the Power System Diagram Looks:

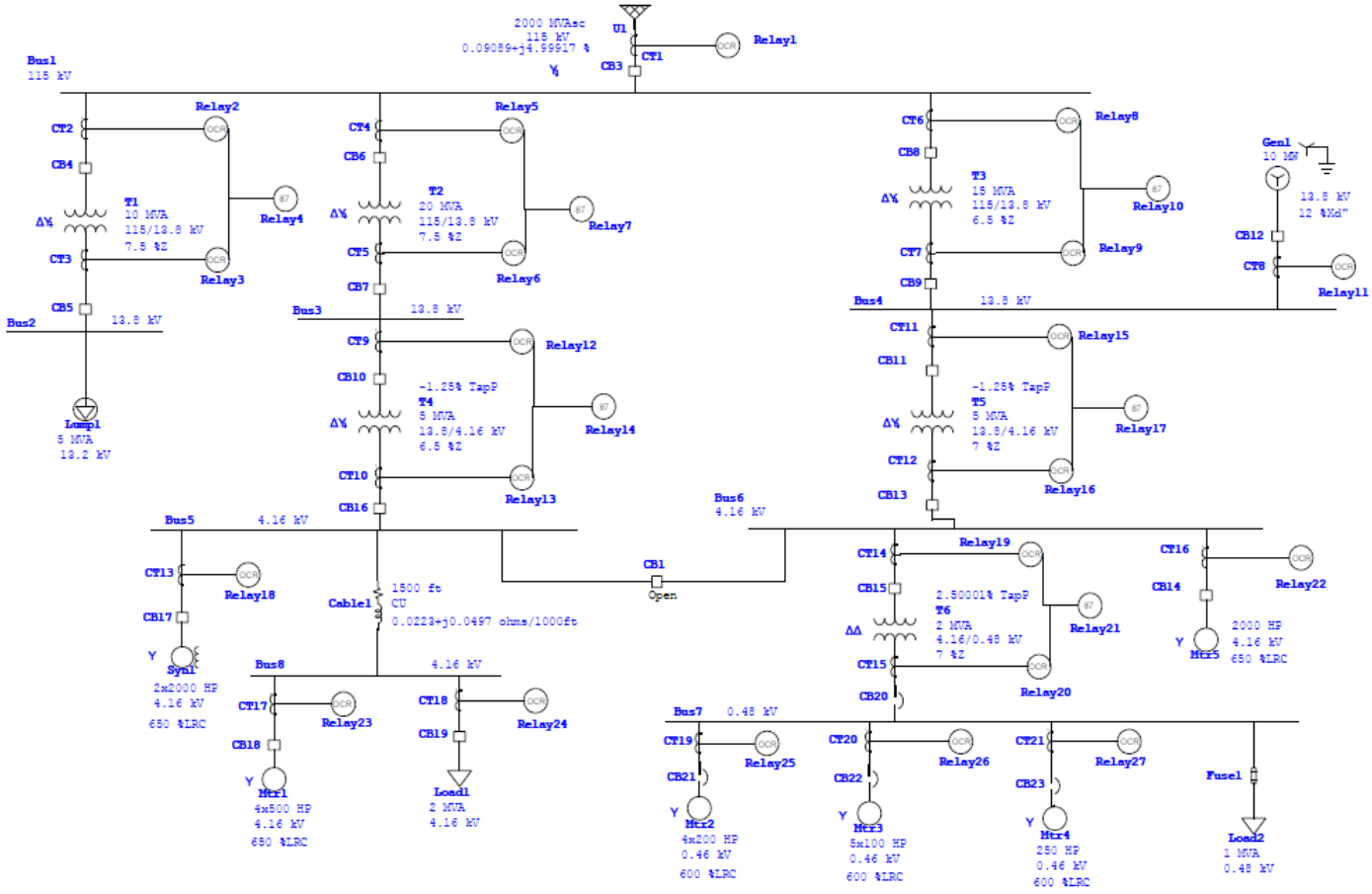

Fig. 24 Power System Diagram After adding CT's & Relays (CB-1 Open Configuration)

Now it's time to select Relay Model from ETAP Library & to Calculate I_{Pickup} For Each Component, From I_{Pickup} we get Pickup Value.

To calculate I_{pickup} we use the following relation,

$$\mathbf{2 \times I_{Max\text{-}Load} < I_{Pickup} < 1/3 \times I_{Max\text{-}Fault}}$$

<u>For Power Grid U1 (Main Source):</u>

As I_{Pickup},

$$2 \times I_{Max\text{-}Load} < I_{Pickup}$$

$$2 \times 79.7 < I_{Pickup}$$

$$159.4 < I_{Pickup}$$

For T1 (High Voltage Side):

$$2 \times 26 < I_{Pickup}$$

$$52 < I_{Pickup}$$

For T1 (Low Voltage Side):

$$2 \times 216.9 < I_{Pickup}$$

$$433.8 < I_{Pickup}$$

For T2 (High Voltage Side):

$$2 \times 36.5 < I_{Pickup}$$

$$73 < I_{Pickup}$$

For T2 (Low Voltage Side):

$$2 \times 304.4 < I_{Pickup}$$

$$608.8 < I_{Pickup}$$

For T3 (High Voltage Side):

$$2 \times 19.4 < I_{Pickup}$$

$$38.8 < I_{Pickup}$$

For T3 (Low Voltage Side):

$$2 \times 176.1 < I_{Pickup}$$

$$352.2 < I_{Pickup}$$

For T4 (High Voltage Side):

$$2 \times 304.4 < I_{Pickup}$$

$$608.8 < I_{Pickup}$$

For T4 (Low Voltage Side):

$$2 \times 1001.2 < I_{Pickup}$$

$$2002.4 < I_{Pickup}$$

For T5 (High Voltage Side):

$$2 \times 176.1 < I_{Pickup}$$

$$352.2 < I_{Pickup}$$

For T5 (Low Voltage Side):

$$2 \times 577 < I_{Pickup}$$

$$1154 < I_{Pickup}$$

For T6 (High Voltage Side):

$$2 \times 335.2 < I_{Pickup}$$

$$670.4 < I_{Pickup}$$

For T6 (Low Voltage Side):

$$2 \times 3036.7 < I_{Pickup}$$

$$6073.4 < I_{Pickup}$$

For Gen1:

$$2 \times 80.4 < I_{Pickup}$$

$$160.8 < I_{Pickup}$$

For Syn1:

$$2 \times 494 < I_{Pickup}$$

$$988 < I_{Pickup}$$

For Mtr1:

$$2 \times 252.5 < I_{Pickup}$$

$$505 < I_{Pickup}$$

For Mtr2:

$$2 \times 997.4 < I_{Pickup}$$

$$1994.8 < I_{Pickup}$$

For Mtr3:

$$2 \times 644.1 < I_{Pickup}$$

$$1288.2 < I_{Pickup}$$

For Mtr4:

$$2 \times 285.2 < I_{Pickup}$$

$$570.4 < I_{Pickup}$$

For Mtr5:

$$2 \times 241.8 < I_{Pickup}$$

$$483.6 < I_{Pickup}$$

For Load1:

$$2 \times 265 < I_{Pickup}$$

$$530 < I_{Pickup}$$

In ETAP, if we enter Pickup value in relay settings then it automatically I_{Pickup}. So, we randomly entered some values for Pickup to get Desired I_{Pickup} for every component. By this Process we got Pickup value for Every Component. So, we make following Table. The specifications of relays also showed in Table.

Sr. No.	Component	Relay ID	Relay Model	Protection Type	I_{Pickup}	Pickup value	Relay Output
1	Power Grid	Relay1	ABB 50D	Time delay over current	159.4<	8	Open CB3
2	Transformer 1 (Primary Side)	Relay2	ABB 50D	Time delay over current	52<	5.3	Open CB4
3	Transformer 1 (Secondary Side)	Relay3	ABB 50D	Time delay over current	433.8<	8.7	Open CB5
4	Transformer 1	Relay4	ABB HU	Differential	-	-	Open CB4-CB5
5	Transformer 2 (Primary Side)	Relay5	ABB 50D	Time delay over current	73<	5.9	Open CB6
6	Transformer 2 (Secondary Side)	Relay6	ABB 50D		608.8<	7.625	Open CB7
7	Transformer 2	Relay7	ABB HU	Differential	-	-	Open CB6-CB7
8	Transformer 3 (Primary Side)	Relay8	ABB 50D	Time delay over current	38.8<	5.2	Open CB8
9	Transformer 3 (Secondary Side)	Relay9	ABB 50D	Time delay over current	352.2<	8.811	Open CB9
10	Transformer 3	Relay10	ABB HU	Differential	-	-	Open CB8-CB9
11	Transformer 4 (Primary Side)	Relay12	ABB 50D	Time delay over current	608.8<	7.65	Open CB10
12	Transformer 4 (Secondary Side)	Relay13	ABB 50D	Time delay over current	2002.4<	9.114	Open CB16
	Transformer 4	Relay14	ABB HU	Differential	-	-	Open CB10-CB16
13	Transformer 5 (Primary Side)	Relay15	ABB 50D	Time delay over current	352.2<	8.9	Open CB11
14	Transformer 5 (Secondary Side)	Relay16	ABB 50D	Time delay over current	1154<	9.664	Open CB13
15	Transformer 5	Relay17	ABB HU	Differential	-	-	Open CB11-CB13
16	Transformer 6 (Primary Side)	Relay19	ABB 50D	Time delay over current	670.4<	8.5	Open CB15
17	Transformer 6 (Secondary Side)	Relay20	ABB 50D	Time delay over current	6073.4<	8.71	Open CB20
18	Transformer 6	Relay21	ABB HU	Differential	-	-	Open CB15-CB20
19	Syn1 (Synchronous Motor)	Relay18	GE Multilin IAC-66M	Time delay over current	988<	9.8	Open CB17
20	Mtr1 (Induction Motor)	Relay23	GE Multilin IAC-66M	Time delay over current	505<	10,9	Open CB18
21	Mtr2 (Induction Motor)	Relay25	GE Multilin IAC-66M	Time delay over current	1994.8<	10	Open CB21

22	Mtr3 (Induction Motor)	Relay26	GE Multilin IAC-66M	Time delay over current	1288.2<	10	Open CB22
23	Mtr4 (Induction Motor)	Relay27	GE Multilin IAC-66M	Time delay over current	570.4<	10	Open CB23
24	Mtr5 (Induction Motor)	Relay22	GE Multilin IAC-66M	Time delay over current	483.6<	10	Open CB14
25	Load1 (Static Load)	Relay24	GE Multilin IAC-66M	Time delay over current	530<	9	Open CB19
26	Gen1 (Generator)	Relay 11	GE Multilin 489	Time delay over current	160.8<	1.62	Open CB12

Table 7 Relay Specifications for each component

Now, it's time to check our protection scheme. Go, to star Protection & Coordination system. Run 3-Phase Symmetrical fault on every Bus one by one and check the tripping operation of Circuit breakers.

FAULT AT BUS 1:

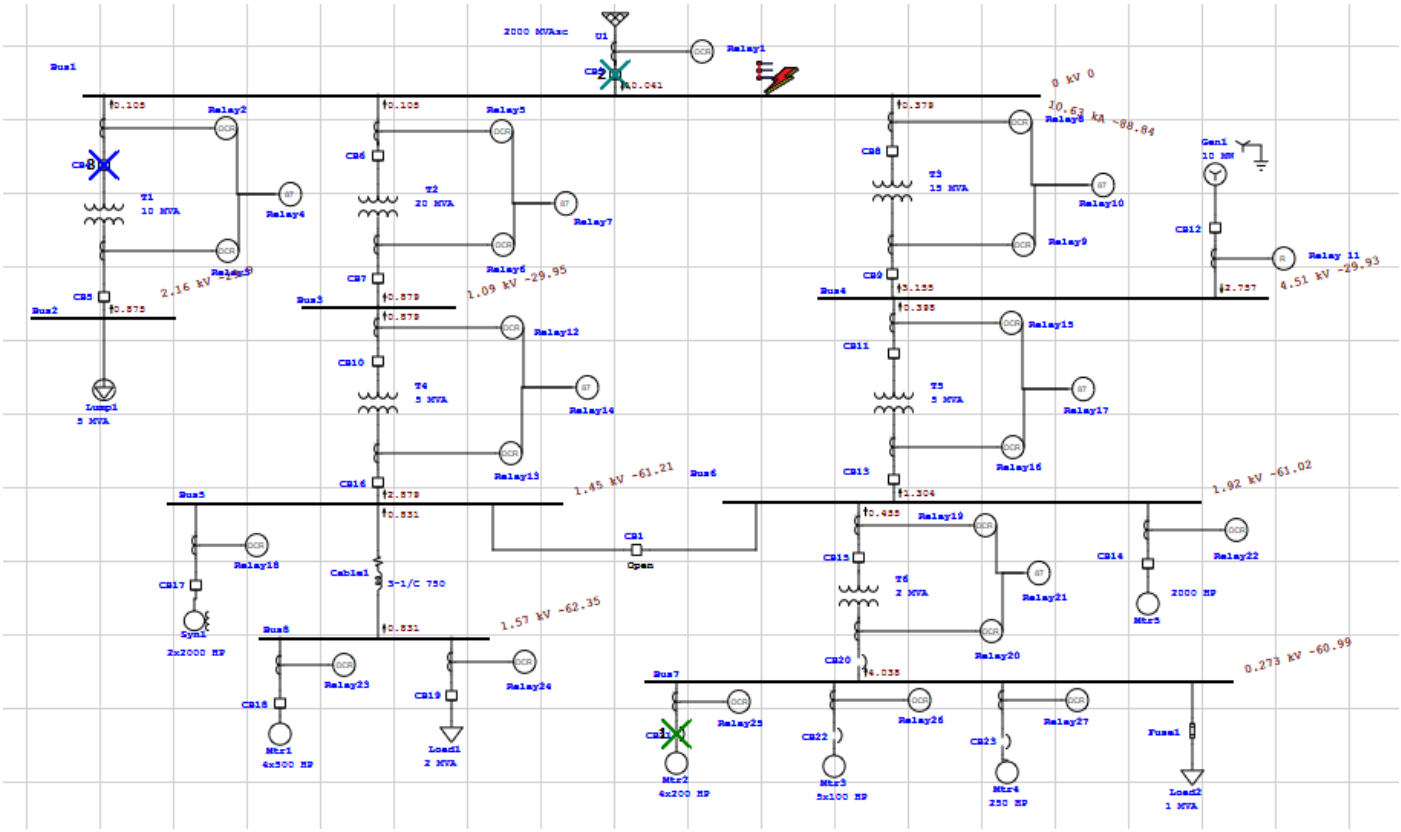

Fig. 25 Fault at Bus 1(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus1

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	10.041	10.0		Phase - OC1 - 50
10.0	Relay2	0.105	10.0		Phase - OC1 - 50
10.0	Relay3	0.875	10.0		Phase - OC1 - 50
10.0	Relay5	0.105	10.0		Phase - OC1 - 50
10.0	Relay6	0.879	10.0		Phase - OC1 - 50
10.0	Relay8	0.379	10.0		Phase - OC1 - 50
10.0	Relay9	3.155	10.0		Phase - OC1 - 50
10.0	Relay12	0.879	10.0		Phase - OC1 - 50
10.0	Relay13	2.879	10.0		Phase - OC1 - 50
10.0	Relay15	0.398	10.0		Phase - OC1 - 50
10.0	Relay16	1.304	10.0		Phase - OC1 - 50
10.0	Relay 11	2.757	10.0		Phase - OC1 - 50
16.2	Relay22	0.85	10.6	16.2	Phase - OC1 - 50
17.7	Relay23	0.831	12.2	17.7	Phase - OC1 - 50
25.0	Relay25	2.093	20.6	25.0	Phase - OC1 - 50
75.0	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB4		83.3		Tripped by Relay2 Phase - OC1 - 50
93.3	CB5		83.3		Tripped by Relay3 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
99.5	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
101	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
2878	Relay 11	2.757	2878		Overload Phase - Thermal
2961	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal
3314	Relay 11	2.757	3314		Phase - OC1 - 51
3397	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 26 Relay Sequence of Operation

FAULT AT BUS 2:

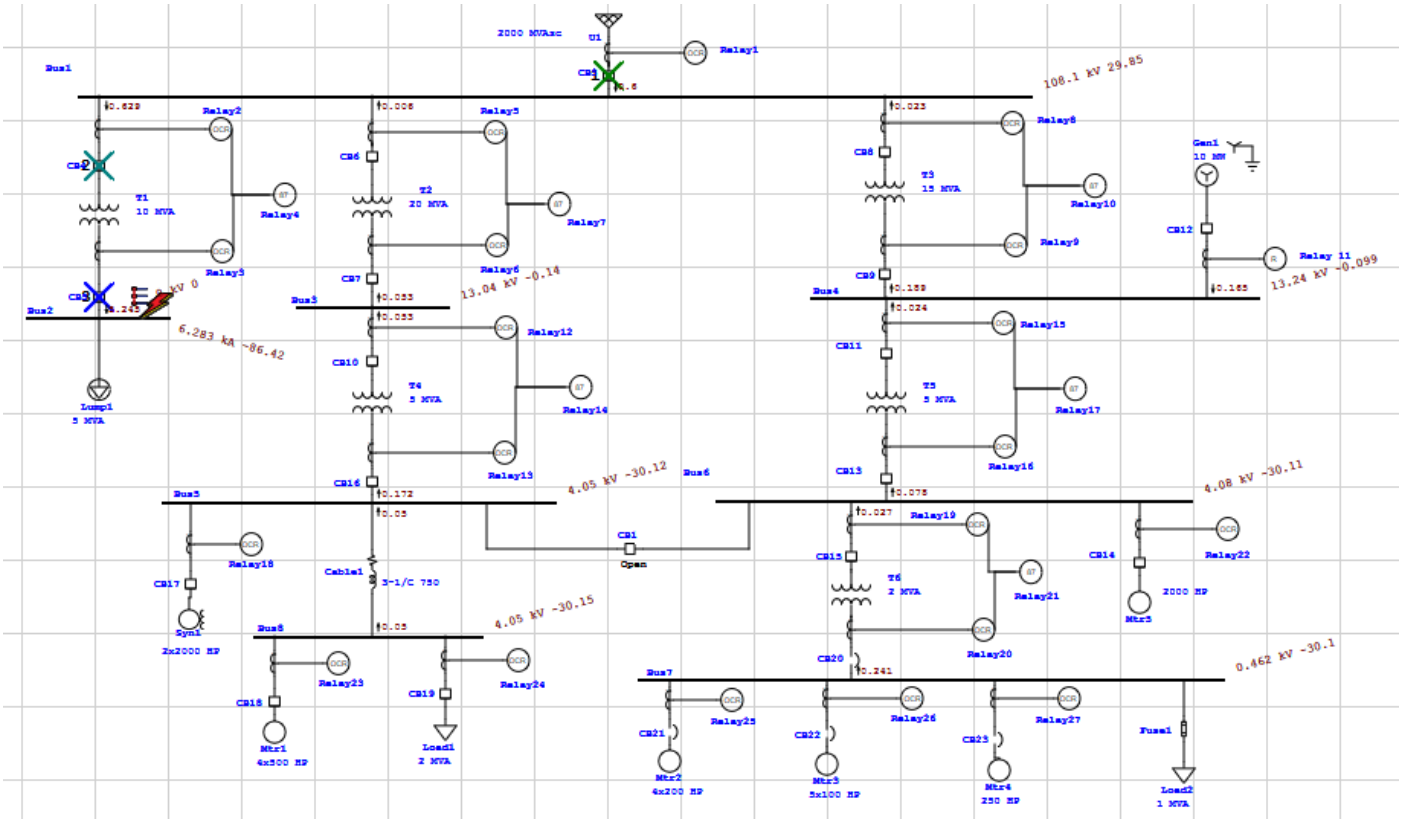

Fig. 27 Fault at Bus 2(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus2

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.6	10.0		Phase - OC1 - 50
10.0	Relay2	0.629	10.0		Phase - OC1 - 50
10.0	Relay3	5.245	10.0		Phase - OC1 - 50
10.0	Relay 11	0.165	10.0		Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB4		83.3		Tripped by Relay2 Phase - OC1 - 50
93.3	CB5		83.3		Tripped by Relay3 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
618385	Relay 11	0.165	> 618385		Phase - OC1 - 51
618468	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 28 Relay Sequence of Operation

FAULT AT BUS 3:

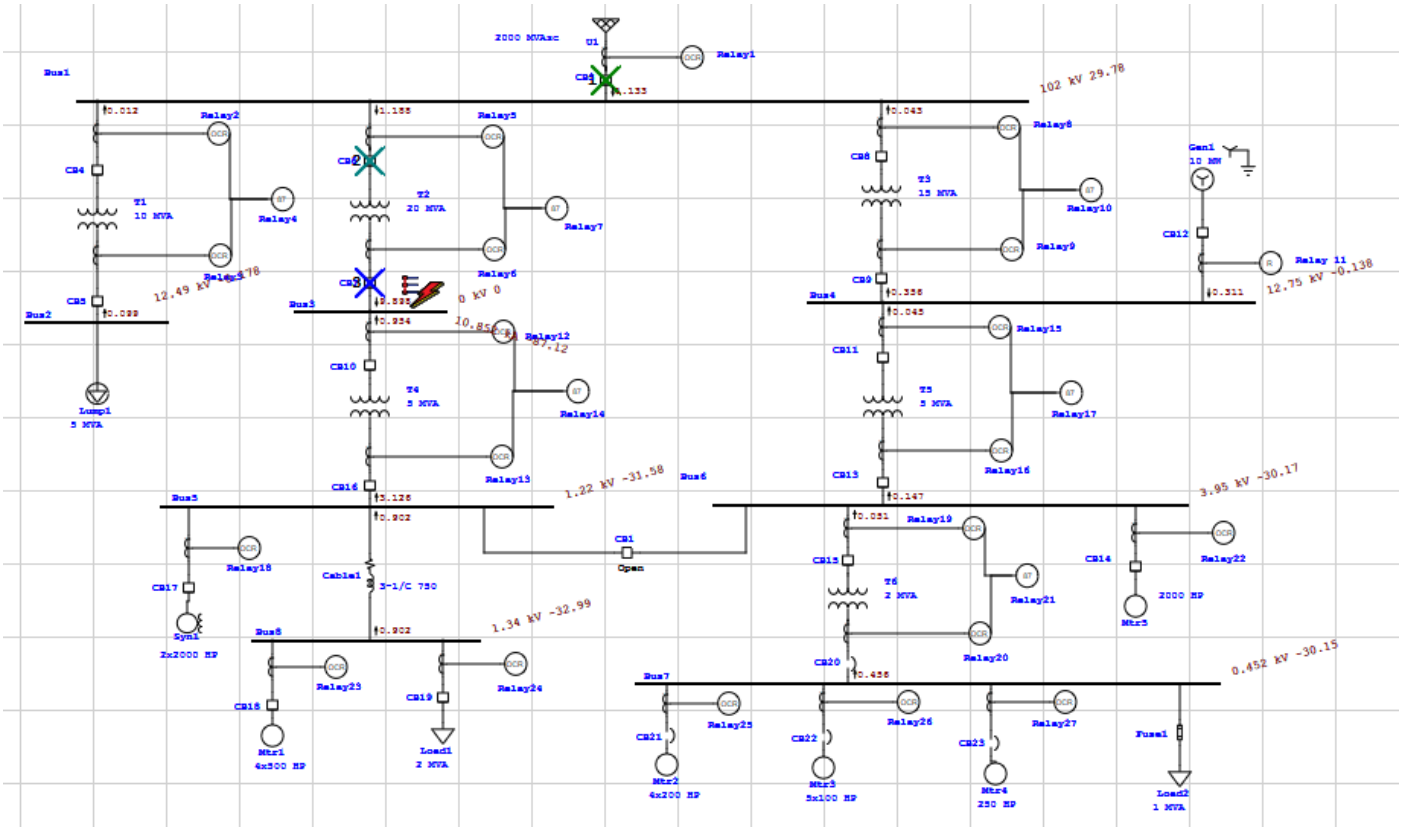

Fig. 29 Fault at Bus 1(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus3

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	1.133	10.0		Phase - OC1 - 50
10.0	Relay5	1.188	10.0		Phase - OC1 - 50
10.0	Relay6	9.898	10.0		Phase - OC1 - 50
10.0	Relay9	0.356	10.0		Phase - OC1 - 50
10.0	Relay12	0.954	10.0		Phase - OC1 - 50
10.0	Relay13	3.126	10.0		Phase - OC1 - 50
10.0	Relay 11	0.311	10.0		Phase - OC1 - 50
16.4	Relay23	0.902	10.9	16.4	Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
99.8	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50
99119	Relay 11	0.311	99119		Phase - OC1 - 51
99202	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 30 Relay Sequence of Operation

FAULT AT BUS 4:

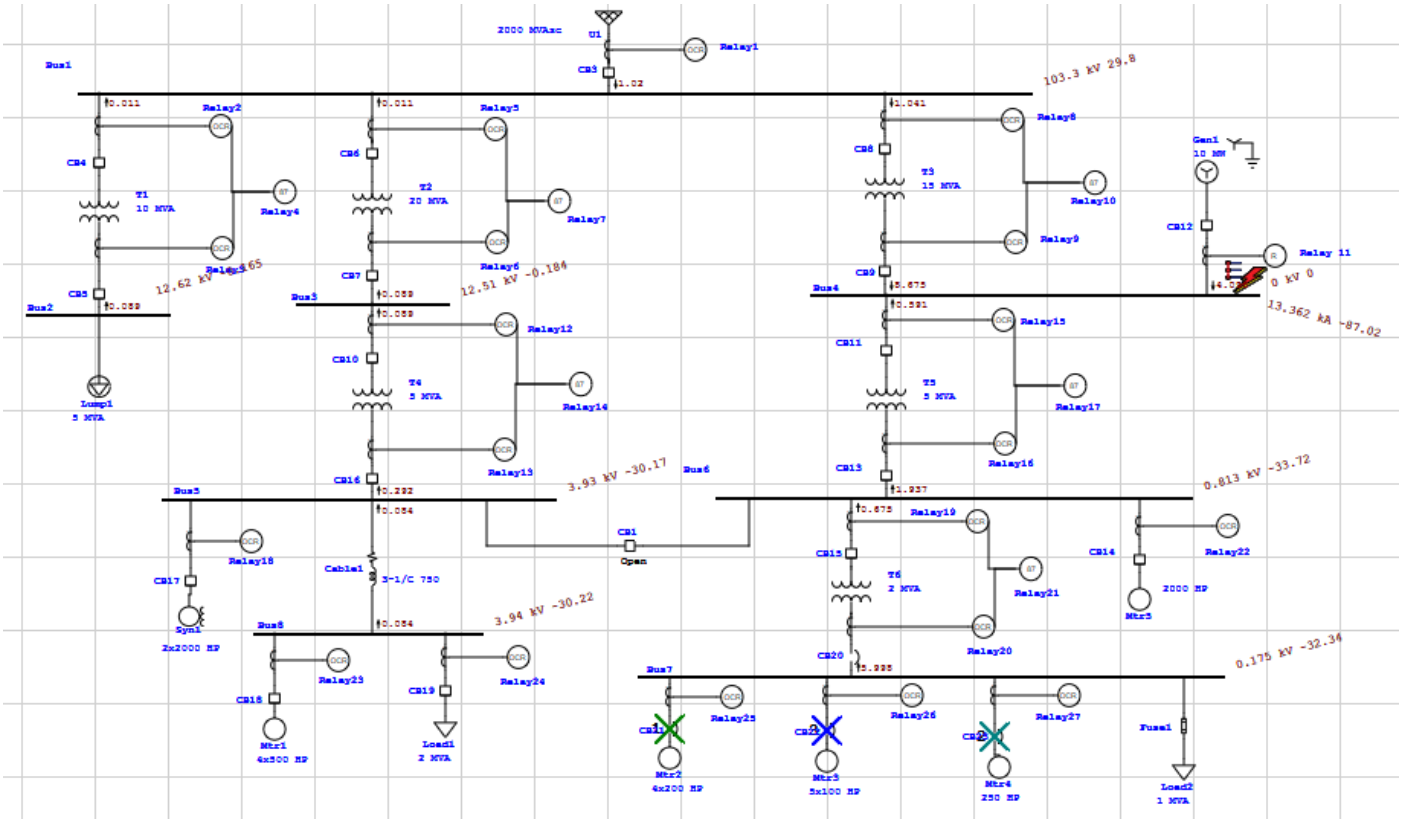

Fig. 31 Fault at Bus 4(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus4

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	1.02	10.0		Phase - OC1 - 50
10.0	Relay8	1.041	10.0		Phase - OC1 - 50
10.0	Relay9	8.675	10.0		Phase - OC1 - 50
10.0	Relay15	0.591	10.0		Phase - OC1 - 50
10.0	Relay16	1.937	10.0		Phase - OC1 - 50
10.0	Relay 11	4.096	10.0		Phase - OC1 - 50
11.9	Relay22	1.263	5.5	11.9	Phase - OC1 - 50
17.5	Relay25	3.11	12.0	17.5	Phase - OC1 - 50
18.3	Relay27	0.89	12.8	18.3	Phase - OC1 - 50
21.3	Relay26	2	16.2	21.3	Phase - OC1 - 50
67.5	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
68.3	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
71.3	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
95.2	CB16		83.3		Tripped by Relay22 Phase - OC1 - 50
1388	Relay 11	4.096	1388		Overload Phase - Thermal
1471	CB12		83.3		Tripped by Relay 11 Overload Phase - Thermal
3043	Relay 11	4.096	3043		Phase - OC1 - 51
3127	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 32 Relay Sequence of Operation

FAULT AT BUS 5:

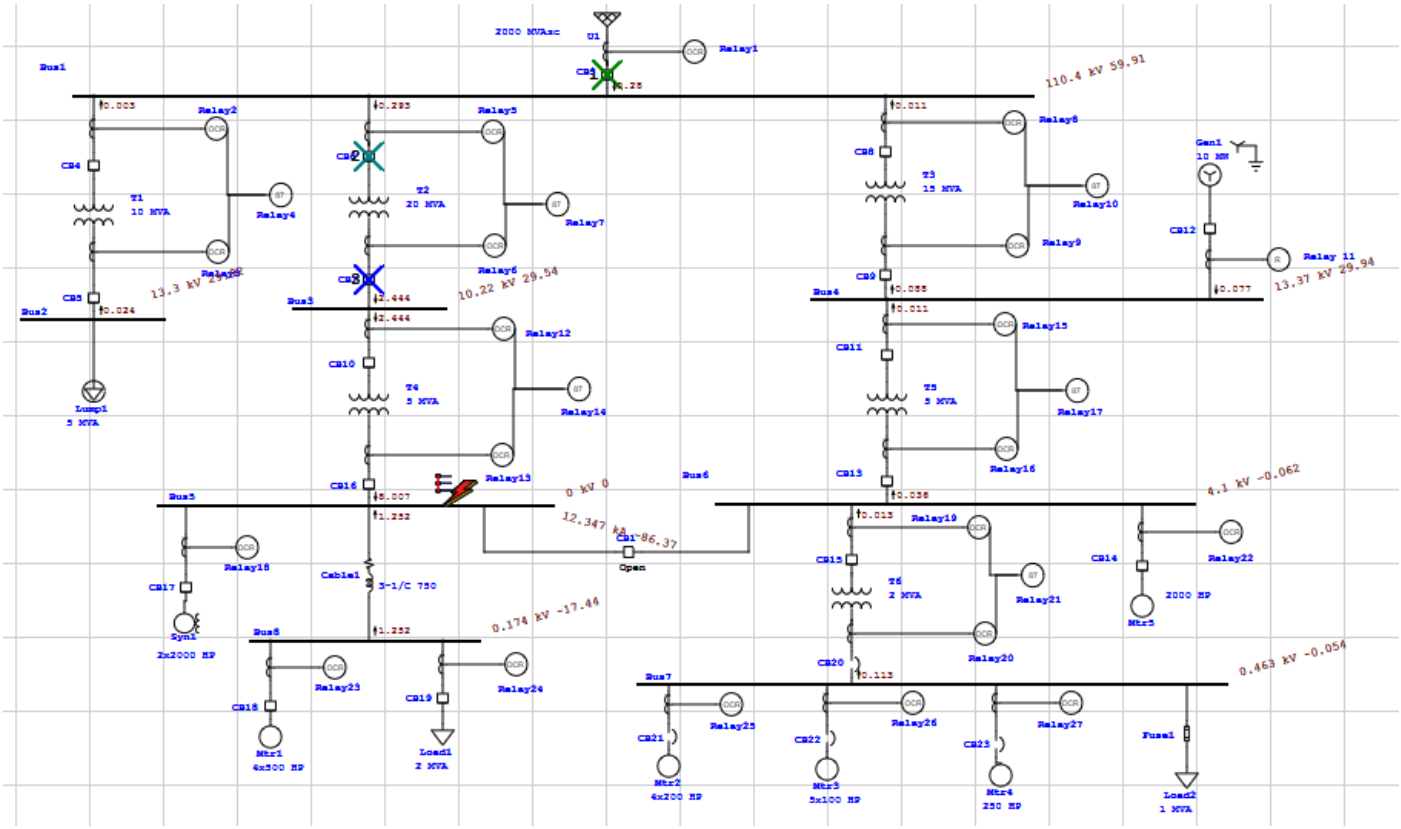

Fig. 33 Fault at Bus 5(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus5

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.28	10.0		Phase - OC1 - 50
10.0	Relay5	0.293	10.0		Phase - OC1 - 50
10.0	Relay6	2.444	10.0		Phase - OC1 - 50
10.0	Relay12	2.444	10.0		Phase - OC1 - 50
10.0	Relay13	8.007	10.0		Phase - OC1 - 50
12.7	Relay23	1.252	6.4	12.7	Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
96.0	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50

Fig. 34 Relay Sequence of Operation

FAULT AT BUS 6:

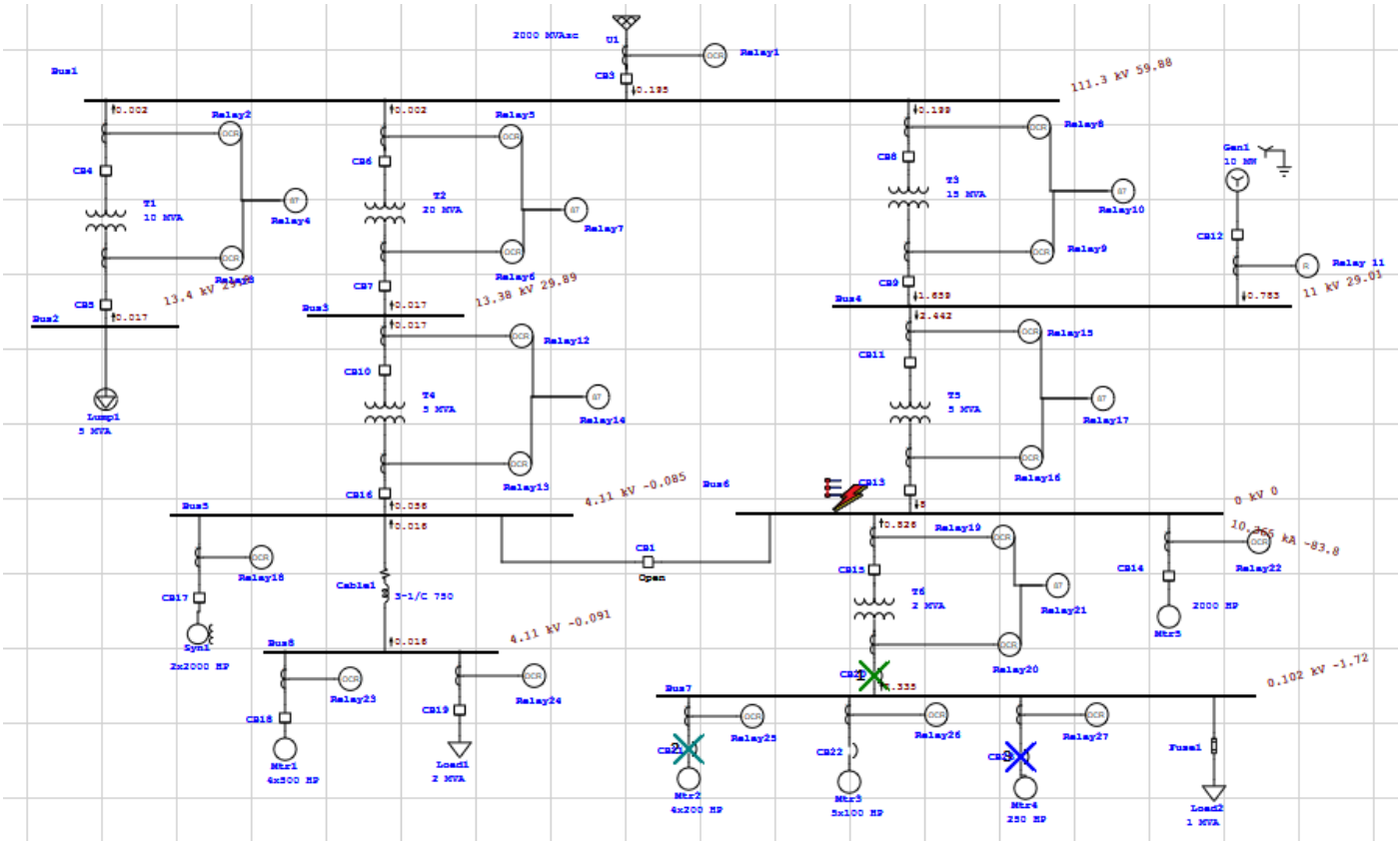

Fig. 35 Fault at Bus 6(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus6

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.195	10.0		Phase - OC1 - 50
10.0	Relay8	0.199	10.0		Phase - OC1 - 50
10.0	Relay9	1.659	10.0		Phase - OC1 - 50
10.0	Relay15	2.442	10.0		Phase - OC1 - 50
10.0	Relay16	8	10.0		Phase - OC1 - 50
10.0	Relay19	0.826	10.0		Phase - OC1 - 50
10.0	Relay20	7.335	10.0		Phase - OC1 - 50
10.0	Relay 11	0.783	10.0		Phase - OC1 - 50
10.3	Relay22	1.545	3.8	10.3	Phase - OC1 - 50
14.8	Relay25	3.803	9.0	14.8	Phase - OC1 - 50
15.3	Relay27	1.088	9.7	15.3	Phase - OC1 - 50
17.8	Relay26	2.446	12.3	17.8	Phase - OC1 - 50
60.0	CB20		50.0		Tripped by Relay20 Phase - OC1 - 50
64.8	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
65.3	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
67.8	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50

93.3	CB8		83.3	Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3	Tripped by Relay9 Phase - OC1 - 50
93.3	CB11		83.3	Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3	Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3	Tripped by Relay16 Phase - OC1 - 50
93.3	CB15		83.3	Tripped by Relay19 Phase - OC1 - 50
93.6	CB16		83.3	Tripped by Relay22 Phase - OC1 - 50
13354	Relay 11	0.783	13354	Phase - OC1 - 51
13437	CB12		83.3	Tripped by Relay 11 Phase - OC1 - 51
57095	Relay 11	0.783	57095	Overload Phase - Thermal
57178	CB12		83.3	Tripped by Relay 11 Overload Phase - Thermal

Fig. 36 Relay Sequence of Operation

FAULT AT BUS 7:

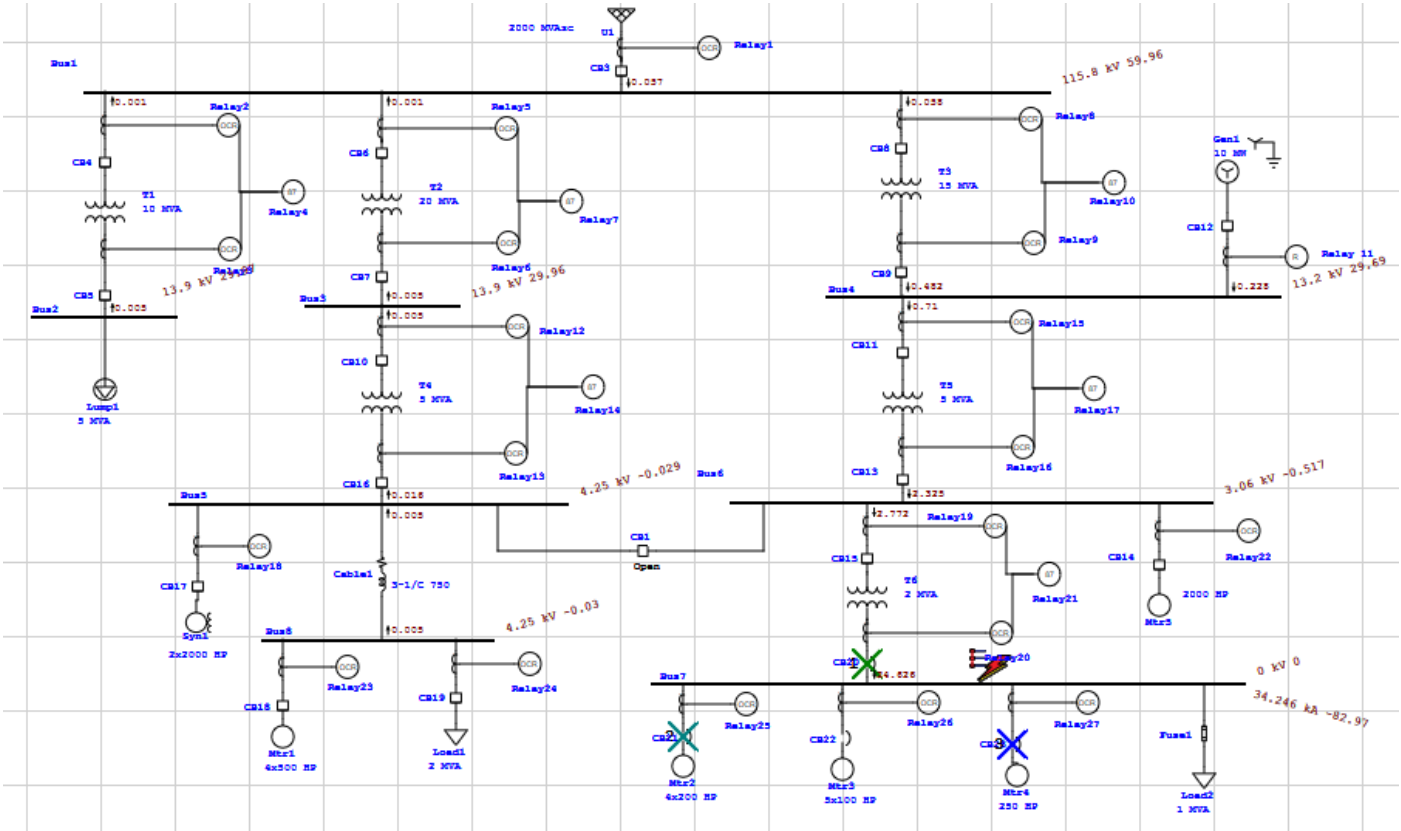

Fig. 37 Fault at Bus 7(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus7

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay8	0.058	10.0		Phase - OC1 - 50
10.0	Relay9	0.482	10.0		Phase - OC1 - 50
10.0	Relay15	0.71	10.0		Phase - OC1 - 50
10.0	Relay16	2.325	10.0		Phase - OC1 - 50
10.0	Relay19	2.772	10.0		Phase - OC1 - 50
10.0	Relay20	24.626	10.0		Phase - OC1 - 50
10.0	Relay 11	0.228	10.0		Phase - OC1 - 50
12.0	Relay25	4.988	5.6	12.0	Phase - OC1 - 50
12.5	Relay27	1.427	6.1	12.5	Phase - OC1 - 50
14.2	Relay26	3.208	8.2	14.2	Phase - OC1 - 50
60.0	CB20		50.0		Tripped by Relay20 Phase - OC1 - 50
62.0	CB21		50.0		Tripped by Relay25 Phase - OC1 - 50
62.5	CB23		50.0		Tripped by Relay27 Phase - OC1 - 50
64.2	CB22		50.0		Tripped by Relay26 Phase - OC1 - 50
93.3	CB8		83.3		Tripped by Relay8 Phase - OC1 - 50
93.3	CB9		83.3		Tripped by Relay9 Phase - OC1 - 50
93.3	CB11		83.3		Tripped by Relay15 Phase - OC1 - 50
93.3	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 50
93.3	CB13		83.3		Tripped by Relay16 Phase - OC1 - 50
93.3	CB15		83.3		Tripped by Relay19 Phase - OC1 - 50
252029	Relay 11	0.228	252029		Phase - OC1 - 51
252112	CB12		83.3		Tripped by Relay 11 Phase - OC1 - 51

Fig. 38 Relay Sequence of Operation

FAULT AT BUS 8:

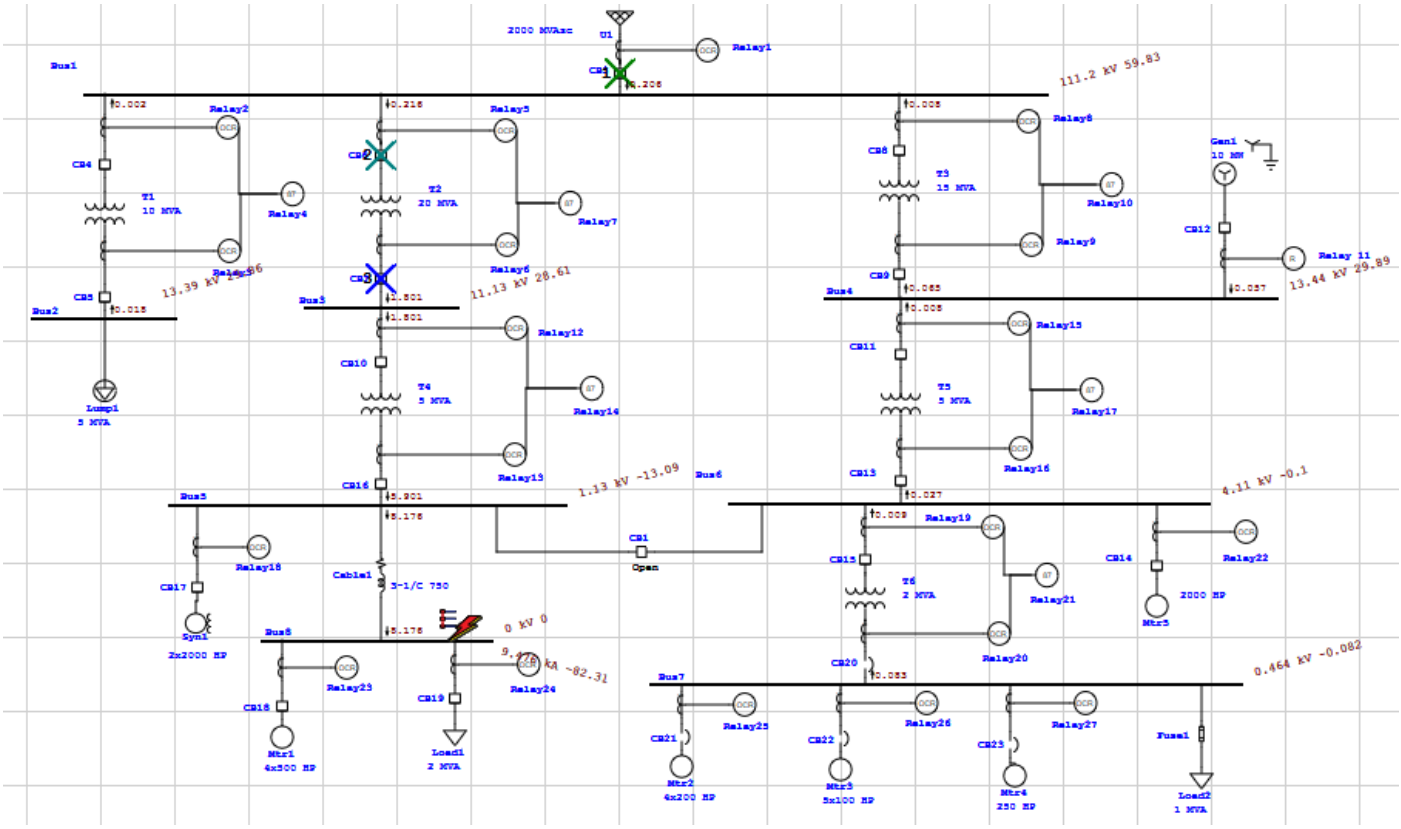

Fig. 39 Fault at Bus 8(CB-1 Open configuration)

Relay Sequence Operation:

3-Phase (Symmetrical) fault on bus: Bus8

Data Rev.: Base Config: Normal Date: 04-15-2021

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Relay1	0.206	10.0		Phase - OC1 - 50
10.0	Relay5	0.216	10.0		Phase - OC1 - 50
10.0	Relay6	1.801	10.0		Phase - OC1 - 50
10.0	Relay12	1.801	10.0		Phase - OC1 - 50
10.0	Relay13	5.901	10.0		Phase - OC1 - 50
12.3	Relay23	1.304	5.9	12.3	Phase - OC1 - 50
93.3	CB3		83.3		Tripped by Relay1 Phase - OC1 - 50
93.3	CB6		83.3		Tripped by Relay5 Phase - OC1 - 50
93.3	CB7		83.3		Tripped by Relay6 Phase - OC1 - 50
93.3	CB10		83.3		Tripped by Relay12 Phase - OC1 - 50
93.3	CB16		83.3		Tripped by Relay13 Phase - OC1 - 50
95.6	CB18		83.3		Tripped by Relay23 Phase - OC1 - 50

Fig. 40 Relay Sequence of Operation
