	X III HYDRO POWER GENERATION PLANT UNIT 7 GENERATOR DAMAGE	**XXXXXXXX**

Document Title	**DOCUMENT No**							
CAUSES OF THE DAMAGE	**PHASE**	**AREA**	**TRAIN/ UNIT**	**DIS**	**DOC**	**SEQ**	**REV**	Page 1 of 121
	IWPRD	01	0001	EL	ST	001	D1	

X MINISTRY OF ENERGY
X WATER & POWER
RESOURCES DEVELOPMENT CO.

X HYDRO POWER GENERATION PLANT
UNIT 7 GENERATOR DAMAGE

DOCUMENT TITLE

CAUSES OF THE DAMAGE

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UNIT 7 GENERATOR DAMAGE

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24	*								74	*						
25	*								75	*						
26	*								76	*						
27	*								77	*						
28	*								78	*						
29	*	**51							79	*						
30	*								80	*						
31	*								81	*						
32	*								82	*						
33	*								83	*						
34	*								84	*						
35	*								85	*						
36	*								86	*						
37	*								87	*						
38	*								88	*						
39	*								89	*						
40	*								90	*						
41	*								91	*						
42	*								92	*						
43	*								93	*						
44	*								94	*						
45	*								95	*						
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Dedicated to my students in Power System Analysis Lab.

Acknowledgments

1. INTRODUCTION

XIII hydro generation plant is designed to produce more than 2000 MW power generation by its 8 generator units. The generation plant is located near to X Village, about 200 km North East of X city.

At 3:30 afternoon of 27-05-2007, normal operation became suddenly disrupted. According to the operators a huge burning fire has come out from unit no.7. The trip was triggered off by the generator relays according to the event lists.

The purpose of this report is to investigate the possible causes of the faults and the design or operation problems related to the event.

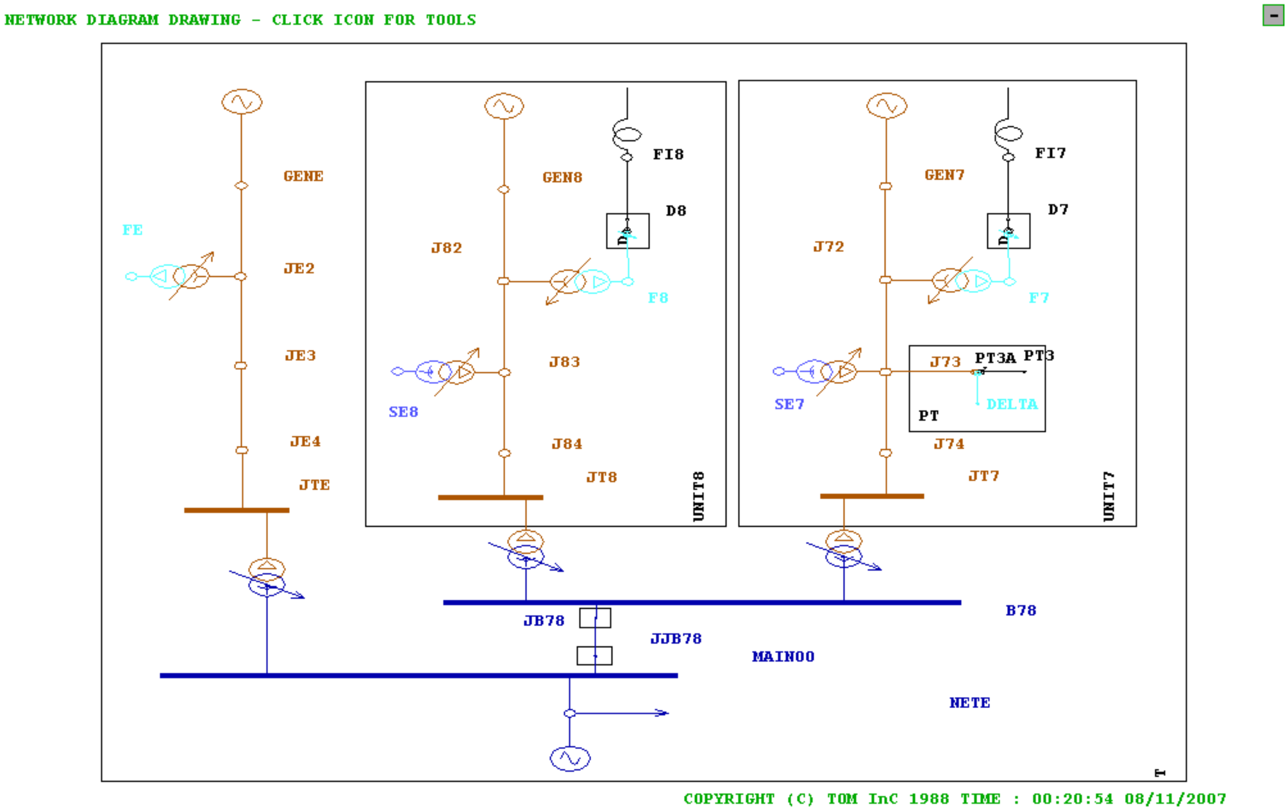
2. SCOPE

The objective of this document is to find out the causes of the events through analysis. In order to investigate the causes of the faults including those related to the operation malfunctions, design problems, protection recovery or tuning problems, studies as described in the followings are performed.

3. SYSTEM DESCRIPTION AND INPUT DATA

Single line diagram as represented in drawing DWG.NO. 12R9-16/E-64-101/D is used to represent the power generation plant inside the simulation program (PASHA). Figure 1 shows the representation of the plant while unit no.7& 8 are represented in details and other units (those which are operating at the instant of the accident) are represented as equivalent generator and transformer (4 other generators and 4 other unit transformers were in service). Xian national grid as viewed from X III entering busbar is represented by an equivalent generator on 400KV incoming busbar.

Final data sheet of the generator (Drwg. No. 5-995.080) is used to provide the generator and its excitation data. Excitation system documentation components (letter no: K3 AG FB A 0494.DOC) is also employed to fulfil the data for the excitation system. Document 1KHF601002 from ABB is used to find out the settings of the protection system REG216. Relay software's Win-eve and HMI are used to find out other protection settings and records. Unit transformer resistance and reactances are extracted from these documents. Those equipment or loads that were not in the category of the studies intended are either ignored or represented by their equivalent.



NETWORK DIAGRAM DRAWING - CLICK ICON FOR TOOLS

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Figure1. The representation of the plant in PASHA simulation program

The following parameter values are used as input data base and INPUT DATA:

CABLES AND LINES DATA BASE

CABLE		PASHA LIB.	RATING MVA	RATING KV	RESISTANCE PU/KM	REACTANCE PU/KM	SUSEPTANCE PU/KM	ZERO SEQUENCE RESISTANCE-PU/KM	ZERO SEQUENCE REACTANCE-PU/KM
SIZE	MANUFACT.								
fictious		15	100	15.75		0.0001			0.0001
	CURLEW	2	100	400	0.00002	0.0002	0.0053	0.0002	0.00063
fictious		16	100	15.75		0.0001	0.0012		0.0001
fictious		2	100	400	100		0.0001		0.0001

Note : RATING MVA IS OBTAINED FROM CABLE CURRENT CAPACITY, RATINGS ARE THE PU BASES

TRANSFORMERS DATA BASE

RATING KVA	U1/U2 KV/KV	CONNECTION TYPE **	PASHA LIB.	RESISTANCE PU	REACTANCE PU	ZERO SEQUENCE		MINTAP	TAP STEP	MAXTAP	RATIO DV	BASE MVA	MANUFACT.
						RESISTANCE PU	REACTANCE PU						
300000	410/15.75	XD11	1	0.008	0.14979	0.008	0.12975	-5	2.5	5	-0.03	300	
1095	0.35/15.75	YD5*	2	0.006	0.06			-5	2.5	5	0	1.095	
1600	15.75/3.3	DX1	3		0.06		0.06	-5	2.5	5	0	1.6	

***DY11=DY5, DY1=DY7, X=Yn**

GENERATOR DATA BASE

RATED POWER MVA	TYPE	RATED VOLTAGE KV	PASHA LIB.	RESISTANCE PU	REACTANCE PU	ZERO SEQUENCE RESISTANCE- PU	ZERO SEQUENCE REACTANCE- PU	H (SEC)
263	Saturated*	15.75	7	0.0025	0.892	2780.1**	0.094	
263	unsaturated	15.75	71	0.0025	1.065	2780.1**	0.094	

PASHA LIB.	DIRECT AXIS					QUADRATURE AXES			
	X'd	τ'd	X"d	τ"d	Xq	X'q	τ'q	X"q	τ"q
7	0.229	10.8	0.2	0.0415	0.6				
71	0.249	10.8	0.23	0.0415	0.656				

*saturated values are used no poiter reactance has been introduced in program to consider the saturation effect

****0.59 Ohm grounding resistor considered in secondary of a 16/1.73KV / 240V from primary 874.07 Ohm. The P.U. value is 926.7 and the 3*R that is 2780.1 P.U. is represented as zero sequence resistance.**

Figure 2. PASHA/UDEM model of Frequency/Load control loop for hydro turbine. Not required in the analysis performed

Figure 3. PASHA/UDEM model of Automatic voltage regulator and excitation system. Not required in the analysis performed.

INPUT DATA

```
===========================
0SYSTEM TITLE: X 7,8,E WITH PT
0STUDY TITLE:

 SYSTEM MVA BASE = 100.000


 PASHA ACTUAL DYNAMIC FAULT IS ACTIVE


 B U S B A R    D A T A    I N P U T
 -------------------------------------

 S Y N C H R O N O U S    G E N E R A T O R S

             GENERATION        GENERATOR IMPEDANCES PU      O-C TIME CONST
  BUSBAR       P        Q      RES     SYN-X  DA-TR-X DA-ST-X  TDO'     TDO"     AREA
   NAME      (MW)    (MVAR)     R       XD      XD'     XD"    (MSEC)   (MSEC)

 GEN7      280.00    82.15  0.0010  0.3392  0.0871  0.076010800.00    41.50   UN7
 GENE     1034.00  156.70  0.0010  0.3392  0.0871  0.076010800.00    41.50   UNE
      WARNING - TDO' OF FOLLOWING MACHINE MISSING
 NETE    31417.9216941.90  0.0009  0.0058  0.0058  0.0000     0.00     0.00   UNE
 GEN8      280.00    41.98  0.0010  0.3392  0.0871  0.076010800.00    41.50   UN8

 END OF SYNCHRONOUS MACHINE DATA


 S T A T I C    L O A D S

  BUSBAR          LOAD           INITIAL VOLTAGES            AREA
   NAME      P(MW)  Q(MVAR)     MAG(PU)  ANG(DEG)  VNOM.(KV)

 GEN7         0.00     0.00      1.0100   8.251     15.750    UN7
 J72          0.00     0.00      1.0099   8.235     15.750    UN7
 J73          0.00     0.00      1.0098   8.219     15.750    UN7
 J74          0.00     0.00      1.0098   8.203     15.750    UN7
 JT7          0.00     0.00      1.0097   8.188     15.750    UN7
 NETE     33000.0017000.00      0.9965   0.000    400.000    UNE
 GENE         0.00     0.00      0.9900   7.710     15.750    UNE
 JE2          0.00     0.00      0.9899   7.684     15.750    UNE
 JE3          0.00     0.00      0.9899   7.676     15.750    UNE
 JE4          0.00     0.00      0.9899   7.667     15.750    UNE
 F7           0.00     0.00      0.9582   8.528      0.350    UN7
 FE           0.00     0.00      0.9899   7.684      0.350    UNE
 JTE          0.00     0.00      0.9899   7.658     15.750    UNE
 FI7          0.00     0.00      0.6750   8.528      0.280    UN7
 D7           0.00     0.00      0.9582   8.528      0.280    D
 SE7          0.00     0.00      1.0098   8.219      3.300    UN7
 B78          0.00     0.00      0.9968   0.124    400.000    UNE
 GEN8         0.00     0.00      0.9900   8.480     15.750    UN8
 J82          0.00     0.00      0.9900   8.464     15.750    UN8
 J83          0.00     0.00      0.9899   8.448     15.750    UN8
 J84          0.00     0.00      0.9899   8.431     15.750    UN8
 JT8          0.00     0.00      0.9898   8.415     15.750    UN8
 F8           0.00     0.00      0.9392   8.757      0.350    UN8
 FI8          0.00     0.00      0.6616   8.757      0.280    UN8
 D8           0.00     0.00      0.9392   8.757      0.280    D
 SE8          0.00     0.00      0.9899   8.448      3.300    UN8
 MAIN00       0.00     0.00      0.9965   0.009    400.000    UNE
```

```
PT3         0.00    0.00     1.0098   8.219      0.110   PT
PT3A        0.00    0.00     1.0098   8.219      0.110   PT
DELTA       0.00    0.00     1.0098   8.219      0.367   PT
JB78        0.00    0.00     0.9967   0.118    400.000
JJB78       0.00    0.00     0.9965   0.015    400.000

END OF STATIC LOAD DATA


I N D U C T I O N    M O T O R S

              LOAD                        MOTOR IMPEDANCES PU
 BUSBAR   TYPE       P       Q        STATOR          ROTOR 1         ROTOR 2     MAGNETISING  AREA
  NAME   PASHA     (MW)   (MVAR)    RES     REACT   RES     REACT   RES     REACT      REACT


END OF INDUCTION MACHINE DATA

END OF BUSBAR DATA



B R A N C H    D A T A    I N P U T
-------------------------------------

     BUSBAR                 BRANCH IMPEDANCES  (PU)          TRANSFORMER  AREA-TO-AREA  PASHA TYPE
 FROM       TO         PPS AND NPS         ZPS          SUSC    TAP WINDING
                        R       X       R       X       B       (%)   CODE

GEN7     J72        0.0000  0.0001  0.0000  0.0001  0.0012                UN7    UN7          16.
J72      J73        0.0000  0.0001  0.0000  0.0001  0.0000                UN7    UN7          15.
J73      J74        0.0000  0.0001  0.0000  0.0001  0.0000                UN7    UN7          15.
J74      JT7        0.0000  0.0001  0.0000  0.0001  0.0000                UN7    UN7          15.
GENE     JE2        0.0000  0.0000  0.0000  0.0000  0.0252                UNE    UNE          16.
JE2      JE3        0.0000  0.0000  0.0000  0.0000  0.0000                UNE    UNE          15.
JE3      JE4        0.0000  0.0000  0.0000  0.0000  0.0000                UNE    UNE          15.
J72      F7         0.5479  5.4795  0.0000  0.0000  0.0000   0.0   YD11   UN7    UN7           2.
JE2      FE         0.1370  1.3699  0.0000  0.0000  0.0000   0.0   YD11   UNE    UNE           2.
JE4      JTE        0.0000  0.0000  0.0000  0.0000  0.0000                UNE    UNE          15.
FI7      FI7        0.0000 71.5000  0.0000  0.0000  0.0000                UN7    UN7           0.
D7       FI7        0.0000 30.0000  0.0000  0.0000  0.0000                D      UN7           0.
F7       D7         0.0000  0.0001  0.0000  0.0000  0.0000   0.0          UN7    D             0.
J73      SE7        0.0000  3.7500  0.0000  3.7500  0.0000   0.0   DX1    UN7    UN7           3.
B78      JT7        0.0027  0.0499  0.0027  0.0433  0.0000   0.0   XD11   UNE    UN7           1.
GEN8     J82        0.0000  0.0001  0.0000  0.0001  0.0012                UN8    UN8          16.
J82      J83        0.0000  0.0001  0.0000  0.0001  0.0000                UN8    UN8          15.
J83      J84        0.0000  0.0001  0.0000  0.0001  0.0000                UN8    UN8          15.
J84      JT8        0.0000  0.0001  0.0000  0.0001  0.0000                UN8    UN8          15.
J82      F8         0.5479  5.4795  0.0000  0.0000  0.0000   0.0   YD11   UN8    UN8           2.
FI8      FI8        0.0000 71.5000  0.0000  0.0000  0.0000                UN8    UN8           0.
D8       FI8        0.0000 30.0000  0.0000  0.0000  0.0000                D      UN8           0.
F8       D8         0.0000  0.0001  0.0000  0.0000  0.0000   0.0          UN8    D             0.
NETE     MAIN00     0.0000  0.0000  0.0000  0.0000  0.0000                UNE    UNE           0.
MAIN00   JTE        0.0007  0.0125  0.0007  0.0108  0.0000   0.0   XD11   UNE    UNE           1.
B78      JT8        0.0027  0.0499  0.0027  0.0433  0.0000   0.0   XD11   UNE    UN8           1.
J83      SE8        0.0000  3.7500  0.0000  3.7500  0.0000   0.0   DX1    UN8    UN8           3.
PT3      PT3A       0.0000  0.1000  0.0000 40.0000  0.0000   0.0   DX1    PT     PT            4.
PT3A     J73        0.0000  0.1000  0.0000  0.1000  0.0000   0.0   XX0    PT     UN7           4.
PT3A     DELTA      0.0000  0.1000********  0.0000  0.0000   0.0   XD11   PT     PT            5.
JB78     B78        0.0000  0.0000  0.0000  0.0000  0.0006                       UNE           2.
MAIN00   JJB78      0.0000  0.0000  0.0000  0.0000  0.0006                UNE                  2.
JJB78    JB78       0.0000  0.0003  0.0003  0.0008  0.0112                                     2.


END OF BRANCH DATA
```

3.1 REPORTS AVAILABLE

Prior to the start of the studies the following reports about the events were issued and were made available to us at September 2007:

a) Failure in unit 7 of X generation plant
b) Report of the event of unit 7 and its causes.
c) Analysis of the event on unit 7
d) Technical report about the short circuit fault in unit 7 of the generation plant – In Persian – Issued by Mahab Ghods
e) Protection relay response during the event – In Persian – Issued by ABBNIRO
f) Generator damage of 27.05.2007 HEPP X III /Unit 7 description of damage and analysis of possible fault causes – In English- Issued by ANDRITZ VA TECH HYDRO (through Elin)

3.2 RECORDS AVAILABLE

Apart from the drawings and the data sheets of the plant components, the following records and observations are used to provide the conclusions:

a) A site visit
b) Event list (table AX.1)
c) Records of the fault currents and voltages from REG216 (figure 2)
d) Phase S of the X-Y line surge arrester shows a lightening discharge. The discharge had been happened between 16.1.86 till 12.6.86 (Persian dates)
e) Phase S of the Unit 8 surge arrester shows three lightening discharges. The discharge had been happened between 15.2.86 till 15.4.86 (Persian dates)
f) The stator damage pictures (figure 3)
g) The field damage pictures (figure 4)
h) Manual records of main data (currents, voltages, etc) of each half hours, written by operators
i) Test are conducted in Unit no. 8 to tune the record values (because of the error recognized in the measuring devices)
j) Measurements are conducted to find out some of the component characteristics. They are used in this document as the case will arise.

Figure 2: REG216 records

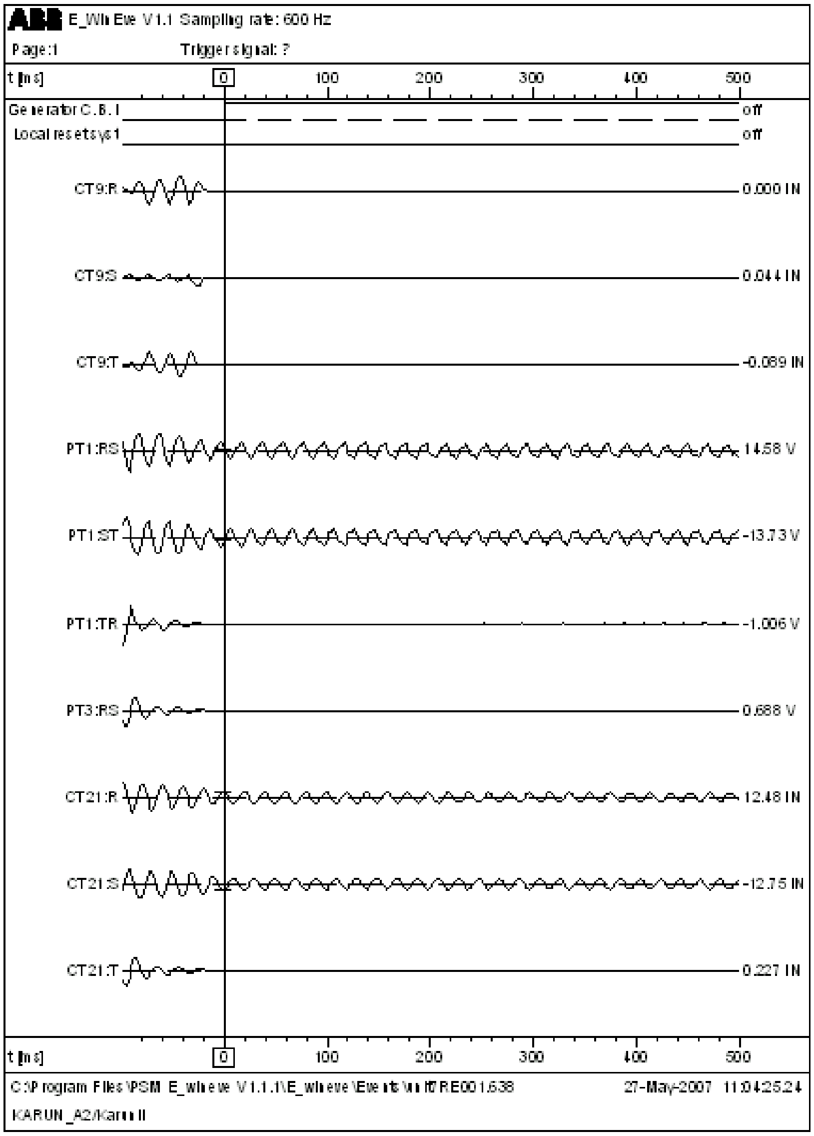


Figure 3: Stator damages

Figure 4: Field damages

4. MODELLINGS AND SIMULATION RESULTS

The following simulation studies are used:

1) Appendix I manipulates the three phase instantaneous values of the currents and voltages which are shown in figure 2 (i.e. the only available record of the event) in order to provide some other useful variables such as the active and reactive powers, zero sequence currents, etc, before and during the events. Tables AI.1 and AII.2 show the results obtained. The start time is selected to be -98.4/-98.3 (will be used here as the time zero) and the time interval is 0.1 msec. The formula used to find out the required variables are described in appendix I.
2) The same results as the case (1) above, is shown in table AII.2 while CT modelling and its transient response are used to extract the CT errors and to find out the primary currents from the secondary currents. CT model is described in appendix II.
3) Load flow studies prior to the fault are described in appendix III.
4) Fault studies including intermediate faults inside the generator are performed, in order to find a clear insight into the sequence of the events. These studies are also described in appendix III.
5) The transient behaviour of the generator and its field are simulated in appendix IV, in order to find out the overvoltage's which had happened in the field.
6) Fast transient switching studies are performed to find out the stator overvoltages. This is described in appendix V.
7) Theory and the occurrence of the arcing ground phenomena are described in appendix VI.
8) Theory and the occurrence of the Ferro resonance effects are described in appendix VII.
9) Generator winding connection, described in appendix VIII.
10) Weather condition and lightening possibility is described in appendix VIIII.
11) Protection event lists are discussed in appendix X.

5. SEQUENCE OF THE EVENTS

The following sequence of the events can be recognized:

a) The magnitude of the zero sequence currents shown in Table AII.2, suggest that at the time around 96.5 a single phase fault starts to be initiated. Its minus sign indicates that it is in phase T, because it flows at the same direction of the voltage of the phase T. The amount of zero sequence current (3I0) is about (0.0055*12500=69A). This is the current which comes from the open delta PT (i.e. PT3) which is in the Ferro resonance mode at the time (please refer to appendix VIII). The single phase fault is located in the slot 217 in the first section (number 1) of the winding 3W, near to the power leads of the generator. This is the time that the 64GB shows the existence of a single phase fault.
b) Two milliseconds latter at instant of time (-93.6), an overload has been occurred. This is obvious from the power (S) obtained in table 3 that exceeds 302.45MVA. The overload relay 46 shows the occurrence of the event.
c) At the same instant of time or so, when the single phase fault is well established, the amount of the zero sequence current that comes from the generator would be enough for the 95% earth fault relay to show the

occurrence of the single phase fault. No record is available to lead to a direct conclusion of this event, however, the third harmonic must be eliminated by this relay and hence minimum 3.3 msec. delay of this relay can also be reasonable.

d) The two other phases (R and S) will be separated from the earth and provide a sustained 1.73 P.U. over voltage respect to earth if the single phase fault has enough current to remain. Otherwise the arc will be extinguished (seen at the time -91.7) and the system will restore to the healthy condition. The fluctuation of the zero sequence current till the instant of the two phases fault (-90) is obvious in the table AII.1. .Due to the occurrence arcing ground phenomena together with Ferro resonance of the PT3 which are described in the appendices VII, and VIII, all the phases are separated from the ground and they are ready to restrike a second fault to the ground or to the phase which is already grounded. Since there is no record that shows the phase voltages respect to the ground, these over voltages cannot be addressed in table AII.1.

e) At time -90 two phases fault had occurred between phase R in slot (327) and phase T in slot (326), (please refer to appendix III, which proves the existence of this event). At this instant of time the phase R paths its maximum value with respect to the neutral (and so to the earth) as indicated in table AII.1 and is ready to flash to the nearest ground potential. If we follow up the winding diagram of the generator or the winding table of the generator, shown in figure VIII.1 and table VIII.1, and consider that winding number 1 of 3W of phase T is grounded through the single phase fault at the slot 217, we can conclude that the first adjacent slots that put these two phases (one in ground potential and the other in the overvoltage mode) near to each other will be the slots 327 and 326, number 9 of 2W and number 18 of 2U. Therefore, a flash over between these windings occurred that imposed a two phase fault. This two phase fault, together with single phase fault that already had existed in winding number 1 of phase T (which is now more weaker because of the occurrence of double phase fault) are the only short circuits that existed in the system until it had been opened by the generator circuit breaker. The existence of the two phase fault has been announced by generator differential relay, and the other generator protection systems, (for more information on item (e) please refer to appendixes III and X).

f) Generator circuit breaker and the field circuit breaker are ordered to open at the same instant of time. There is no delay for field opening in the emergency mode and its maximum opening time is 60 msec. At time -37 the Controlling diode of the discharging resistor was damaged under the heavy passing current and field overvoltages caused by stator fault, caused a heavy overvoltage in the field which is responsible for all the damages in the field. (Please refer to appendix IV, which describes the field opening). The field circuit breaker might also open around this time and so prevents further huge overvoltage to build up. There are two reasons that the field is short circuited in this instant of time. The first reason is that the voltage waveforms of the phases are disrupted by harmonic currents (the occurrence of the self excitation). The second reason is that the stator phase S current is going to increase after the field opening, due to the reduction of the back EMF voltages in all phases. Phase R current waveform shows a reduction because it was already under fault and phase T current is remained untouched because of the location of the fault in this phase which eliminates the back EMF effect. The situation is shown in the figures of the appendixes.

Appendix IV calculates the overvoltage's in the field. Due to these over voltages two flashovers are made their paths to the ground. Figure 4 shows the damages of these faults. The same overvoltage or those which are stem from the stator overvoltage described in sections (i), (j) below, had enough over voltage strength to damage the No 25 field winding and connect it to the earth.

The above discussion is still valid, if the field circuit breaker had been opened latter in time 134msc after the event.

g) At time -25 GCB opens the incoming phase T. No over voltages can be occurred, since this phase is already grounded in its first winding.

h) At time -17 GCB opens the remaining two phases. There is no overvoltage in phase S because of the existence of the back EMF in this phase. The situation is not the same for phase R in 2U winding, since about 25% (18*100/72) of this winding is already earthed though single phase fault of phase T. The back EMF between the power lead and 25% of the winding is very weak and opposes the incoming system EMF because of the fault current direction, therefore not only it does not prevent the occurrence of the subsequent overvoltages but also it contributes to the occurrence of the over voltages that are going to be established in the outgoing part of the 2U winding (other parallel windings in this phase have enough back EMFs).

i) Opening of phase R produced a very large over voltages in this phase due to the presence of 25% of the remaining inductance and the system capacitance. This is fully described in Appendix V. The frequency is about 14KHZ and the over voltages is more than 55KV. The current of this high frequency oscillation goes through the weak earth fault point in phase T and produce the welding damages that are like an old women hair!

j) This huge high frequency overvoltage had exploded the partial discharge capacitor of this phase CC2, which can resist only 50KV. It also needs to find a path to the ground to discharge. At the time, there were two grounds available. One in the T phase due to already single phase ground fault which are scattered in the path and the other through DE winding cover (as indicated in the ELIN's report it consist completely of metal). Therefore, a top bar 127 is faulted to the top bar 126 which has also connected to the neutral through earthling transformer. The bottom bar 127 made a path to the DE metal cover and due to its high frequency nature melted the sharp sections of metal cover when arc was established and found its path to the strongest ground point. The scattering of high frequency melting can be seen in the outgoing plates. The high frequency shocks had caused the complete destruction of oil mist distracter and its other belongings.

6. CAUSE OF INITIAL SINGLE PHASE FAULT IN PHASE T

The damages already described in section 5, are all started from a single phase fault in the first winding of 3W of phase T. The objective of this part is to investigate the causes of this event.

There are three possibilities for the initial single phase fault:

1- The overheating of the windings
2- The overvoltages that stem from ferroresonace effect
3- The lightening strike, induced an overvoltage in the generator

The first cannot be proved through simulation.
The second one is possible, because of the losing currents and loose connection of the earthing in PT3 (please refer to appendix VIII). To prove this we need more elaborate simulation analysis, not preceded in this document.
The third one is also possible; please refer to appendix VIIII for weather condition. The simulation of this phenomenon is also not preceded in this document.

7. CONCLUSION

The causes of the intermediate faults inside the generator are discussed. Sections 5 and 6 show the sequence of the events. The followings are the major causes of the events:

1) Single phase fault in phase T of stator, is established by either Ferroresonance or lightening or overheating
2) Two phase fault has occurred because of arcing ground and ferroresonance
3) Field damages have occurred because of overvoltages in the field caused by controlling diodes of discharging resistors and field opening under the fault
4) Stator damages are occurred because of faults and overvoltages caused by GCB opening.

The following must just be further investigated:

1) The IEEE recommendation for selection of PT must be followed in the design stage of the plant.
2) The selection of the earthing resistor
3) The arresters in the path leading to generator units
4) The Generator Circuit Breaker opening process for the generator internal faults
5) The delay for the field opening in case of intermediate fault
6) The possibility of arcing ground phenomena occurrence
7) Some suggestion about digital recording of the REG216 is made in section AIII.4

APPENDIX I

MANUPULASION OF CURRENT AND VOLTAGES WAVEFORM

The only available waveform record from the event is the one that is already shown in Figure 2. Table AI.1 shows the current and voltage instantaneous values extracted from this record. The other parameters defined in this table (and the table AII.2 represented in the next appendix) are defined as the followings:

1. P.U. Base

12500A, 15.75KV for line voltages, 15.75/1.73205 for phase voltage quantities

2. Extracted values

CURSOR	Cursor position
Time	Time of the incident. The opening of GCB is the reference.
time	Time of the incident. Start of the graph is the reference.
Ir	Instantaneous value of current of phase R (C.T. ratio 12500:1)
Is	Instantaneous value of current of phase S (C.T. ratio 12500:1)
It	Instantaneous value of current of phase T (C.T. ratio 12500:1)
Vrs	Instantaneous value of the voltage between phase R and S on base 110V
Vst	Instantaneous value of the voltage between phase S and T on base 110V
Vtr	Instantaneous value of the voltage between phase T and R on base 110V

We have been informed that the following three quantities measurements are unreliable, however, their variations seems to be accurate:

Ifr	Instantaneous value of A.C current goes to the field phase R (C.T. ratio 100:1)
Ifs	Instantaneous value of A.C current goes to the field phase S (C.T. ratio 100:1)
Ift	Instantaneous value of A.C current goes to the field phase T (C.T. ratio 100:1)

3. Calculated values

3I0=Ir+Is+It	3 times of zero sequence current

Vrn (P.U.) Instantaneous value of the voltage between phase R and the neutral of generator
Calculation formula = (Vrs-Vtr) / 110*1.73205
Vsn Instantaneous value of the voltage between phase S and the neutral of generator
Calculation formula = (Vst-Vrs) / 110*1.73205
Vtn Instantaneous value of the voltage between phase T and the neutral of generator
Calculation formula = (Vtr-Vst) / 110*1.73205

P = (Vrn*Ir+Vsn*Is+Vtn*It)*12.5*15.75/1.73205 Active power MW. It is constant and valid for the instantaneous values in three phase system in all conditions)
Q = (Vrs*It+Vst*Ir+Vtr*Is)*12.5*15.75/(1.73205*110) Reactive power MVAR. It is just valid for balanced and without harmonic circuits. The approximation is valid for our purposes.

S = SQRT(P*P+Q*Q) Power generation going to the network. MVA

Vn0 Neutral voltage respect to earth. This is assumed to be 0 before any single phase fault, and it is 1 P.U. in the present of single phase fault. In case of arcing ground, in theory it can increase to even 6 P.U. Here, it is assumed to be 1 P.U., this is the sustained neutral point voltage in the present of a sustained single phase fault. However, if the exact value is required, it can be calculated during the transient phenomena of arcing ground and ferroresonance described in appendixes VI, VII.

S0 = 3I0*Vn0*12.5*15.75/1.73205 MVA going/coming to/from the earth.

Pf = (Vrn*Ifr+Vsn*Ifs+Vtn*Ift)*0.001*15.75/1.73205 Active power of the field MW. It is constant and valid for the instantaneous values in three phase system in all conditions)

Qf = (Vrs*Ift+Vst*Ifr+Vtr*Ifs)*0.001*15.75/(1.73205*110) Reactive power of the field MVAR. It is just valid for balanced and without harmonic circuits. The approximation is valid for our purposes.

Sf = SQRT(Pf*Pf+Qf*Qf) Field power consumption. MVA

St Total MVA produced by generator

Table AI.1 instantaneous values of the recorded data

CURSOR	TIME	Ir	Is	It	Vrs	Vst	Vtr	Irf	Isf	Itf
-984	-98.4	1.123	-0.314	-0.808	63.02	93.68	-158.7	31.57	-12.48	-19.08
-983	-98.3	1.117	-0.303	-0.813	61.4	94.69	-158.1	31.45	-12.16	-19.29
-982	-98.2	1.1	-0.266	-0.83	56.51	97.76	-156.2	31.09	-11.19	-19.9
-981	-98.1	1.081	-0.227	-0.85	51.61	100.8	-154.3	30.72	-10.22	-20.51
-980	-98	1.061	-0.19	-0.87	46.72	103.9	-152.5	30.36	-9.253	-21.12
-979	-97.9	1.041	-0.151	-0.889	41.84	107	-150.6	29.99	-8.282	-21.73
-978	-97.8	1.024	-0.115	-0.906	36.95	110	-148.7	29.63	-7.311	-22.35
-977	-97.7	1.005	-0.075	-0.926	32.06	113.1	-146.8	29.27	-6.343	-22.96
-976	-97.6	0.985	-0.039	-0.945	27.17	116.2	-144.9	28.9	-5.372	-23.57
-975	-97.5	0.968	-0.002	-0.962	22.29	119.2	-143.1	28.54	-4.401	-24.18
-974	-97.4	0.948	0.036	-0.982	17.4	122.3	-141.2	28.18	-3.432	-24.79
-973	-97.3	0.929	0.072	-1.002	12.5	125.4	-139.3	27.81	-2.461	-25.4
-972	-97.2	0.909	0.112	-1.022	7.612	128.5	-137.4	27.45	-1.493	-26.01
-971	-97.1	0.892	0.148	-1.038	2.721	131.5	-135.5	27.08	-0.522	-26.63
-970	-97	0.872	0.188	-1.058	-2.16	134.6	-133.7	26.72	0.446	-27.24
-969	-96.9	0.853	0.224	-1.078	-7.051	137.7	-131.8	26.36	1.417	-27.85
-968	-96.8	0.833	0.263	-1.097	-11.94	140.7	-129.9	25.99	2.388	-28.46
-967	-96.7	0.816	0.3	-1.114	-16.83	143.8	-128	25.63	3.357	-29.07
-966	-96.6	0.788	0.334	-1.123	-21.51	145.3	-124.8	24.99	4.288	-29.37
-965	-96.5	0.755	0.362	-1.123	-26.1	146	-121	24.22	5.203	-29.51
-964	-96.4	0.724	0.392	-1.123	-30.68	146.7	-117.2	23.45	6.115	-29.65
-963	-96.3	0.69	0.421	-1.123	-35.27	147.4	-113.3	22.67	7.03	-29.79
-962	-96.2	0.659	0.451	-1.123	-39.85	148.2	-109.5	21.9	7.943	-29.93
-961	-96.1	0.625	0.479	-1.123	-44.44	148.9	-105.7	21.12	8.858	-30.07
-960	-96	0.595	0.51	-1.123	-49.02	149.6	-101.9	20.35	9.77	-30.21
-959	-95.9	0.561	0.538	-1.123	-53.6	150.3	-98.02	19.58	10.68	-30.35
-958	-95.8	0.53	0.569	-1.123	-58.19	151	-94.19	18.81	11.6	-30.49
-957	-95.7	0.496	0.6	-1.123	-62.77	151.7	-90.35	18.03	12.5	-30.63
-956	-95.6	0.465	0.628	-1.123	-67.36	152.4	-86.52	17.26	13.42	-30.77
-955	-95.5	0.432	0.659	-1.123	-71.94	153.1	-82.69	16.49	14.34	-30.91
-954	-95.4	0.401	0.687	-1.123	-76.53	153.8	-78.86	15.71	15.25	-31.05
-953	-95.3	0.367	0.718	-1.123	-81.11	154.6	-75.02	14.94	16.16	-31.19
-952	-95.2	0.336	0.746	-1.123	-85.7	155.3	-71.19	14.17	17.08	-31.33
-951	-95.1	0.303	0.777	-1.123	-90.28	156	-67.36	13.39	17.99	-31.47

-950	-95	0.272	0.805	-1.123	-94.85	156.7	-63.54	12.62	18.9	-31.61
-949	-94.9	0.232	0.827	-1.109	-97.97	154.8	-58.57	11.64	19.51	-31.25
-948	-94.8	0.196	0.85	-1.092	-101.1	153	-53.62	10.67	20.12	-30.87
-947	-94.7	0.157	0.872	-1.075	-104.2	151.1	-48.65	9.694	20.72	-30.51
-946	-94.6	0.12	0.892	-1.058	-107.3	149.3	-43.69	8.717	21.33	-30.14
-945	-94.5	0.081	0.914	-1.044	-110.4	147.4	-38.73	7.743	21.93	-29.77
-944	-94.4	0.044	0.937	-1.027	-113.5	145.5	-33.77	6.767	22.54	-29.4
-943	-94.3	0.005	0.957	-1.01	-116.6	143.7	-28.81	5.793	23.15	-29.03
-942	-94.2	-0.03	0.979	-0.993	-119.7	141.8	-23.85	4.816	23.75	-28.66
-941	-94.1	-0.067	1.002	-0.979	-122.8	140	-18.89	2.866	24.96	-27.92
-940	-94	-0.106	1.022	-0.962	-126	138.1	-13.93	1.892	25.57	-27.55
-939	-93.9	-0.143	1.044	-0.945	-129.1	136.2	-8.968	0.914	26.18	-27.18
-938	-93.8	-0.182	1.066	-0.929	-132.2	134.4	-4.013	-0.058	26.78	-26.82
-937	-93.7	-0.218	1.086	-0.914	-135.3	132.5	0.952	-1.036	27.39	-26.45
-936	-93.6	-0.258	1.109	-0.898	-138.4	130.7	5.908	-2.009	28	-26.08
-935	-93.5	-0.294	1.131	-0.881	-141.5	128.8	10.87	-2.986	28.6	-25.71
-934	-93.4	-0.334	1.151	-0.864	-144.6	126.9	15.83	-3.943	29.05	-25.2
-933	-93.3	-0.367	1.168	-0.844	-146.9	124.4	20.65	-4.861	29.19	-24.43
-932	-93.2	-0.398	1.168	-0.811	-147.7	120.6	25.17	-5.779	29.33	-23.65
-931	-93.1	-0.426	1.168	-0.78	-148.4	116.8	29.69	-6.699	29.47	-22.88
-930	-93	-0.457	1.168	-0.746	-149.1	113	34.21	-7.617	29.61	-22.1
-929	-92.9	-0.485	1.168	-0.715	-149.9	109.2	38.74	-8.535	29.76	-21.32
-928	-92.8	-0.516	1.168	-0.682	-150.6	105.4	43.26	-9.455	29.9	-20.55
-927	-92.7	-0.544	1.168	-0.651	-151.3	101.6	47.78	-10.37	30.04	-19.77
-926	-92.6	-0.575	1.168	-0.617	-152.1	97.83	52.3	-11.29	30.17	-19
-925	-92.5	-0.603	1.168	-0.586	-152.8	94.03	56.82	-12.21	30.31	-18.22
-924	-92.4	-0.634	1.168	-0.552	-153.5	90.22	61.35	-13.13	30.45	-17.45
-923	-92.3	-0.665	1.168	-0.519	-154.3	86.42	65.88	-14.05	30.59	-16.67
-922	-92.2	-0.693	1.168	-0.488	-155	82.61	70.4	-14.97	30.73	-15.89
-921	-92.1	-0.724	1.168	-0.454	-155.7	78.81	74.92	-15.89	30.87	-15.12
-920	-92	-0.752	1.168	-0.423	-156.5	75.01	79.44	-16.81	31.02	-14.34
-919	-91.9	-0.783	1.168	-0.39	-157.2	71.21	83.97	-17.72	31.16	-13.56
-918	-91.8	-0.811	1.168	-0.359	-157.9	67.41	88.49	-18.64	31.3	-12.79
-917	-91.7	-0.842	1.168	-0.325	-158.6	63.61	93.01	-19.36	31.11	-11.88
-916	-91.6	-0.864	1.156	-0.291	-157.7	59.09	96.57	-19.97	30.74	-10.9
-915	-91.5	-0.884	1.137	-0.258	-155.8	54.22	99.65	-20.59	30.38	-9.921
-914	-91.4	-0.9	1.12	-0.221	-153.9	49.34	102.7	-21.2	30.02	-8.945
-913	-91.3	-0.92	1.1	-0.188	-152	44.46	105.8	-21.82	29.66	-7.965

-912	-91.2	-0.94	1.081	-0.151	-150.2	39.58	108.9	-22.43	29.3	-6.988
-911	-91.1	-0.959	1.061	-0.117	-148.3	34.7	112	-23.04	28.94	-6.009
-910	-91	-0.976	1.044	-0.081	-146.4	29.82	115.1	-23.66	28.58	-5.032
-909	-90.9	-0.996	1.024	-0.047	-144.6	24.94	118.1	-24.27	28.22	-4.053
-908	-90.8	-1.016	1.005	-0.011	-142.7	20.06	121.2	-24.89	27.86	-3.076
-907	-90.7	-1.033	0.987	0.022	-140.8	15.18	124.3	-25.5	27.49	-2.097
-906	-90.6	-1.052	0.968	0.058	-139	10.3	127.4	-26.12	27.13	-1.12
-905	-90.5	-1.072	0.948	0.092	-137.1	5.431	130.4	-26.73	26.77	-0.14
-904	-90.4	-1.092	0.929	0.129	-135.2	0.55	133.5	-27.34	26.41	0.836
-903	-90.3	-1.109	0.912	0.162	-133.3	-4.33	136.6	-27.96	26.05	1.816
-902	-90.2	-1.128	0.892	0.199	-131.5	-9.211	139.7	-28.57	25.69	2.793
-901	-90.1	-1.148	0.872	0.232	-129.6	-14.09	142.8	-29.19	25.33	3.769
-900	-90	-1.165	0.856	0.266	-127.7	-18.96	145.8	-29.3	24.58	4.634
-899	-89.9	-1.168	0.822	0.3	-122.2	-21.96	143.3	-29.42	23.84	5.495
-898	-89.8	-1.168	0.788	0.334	-116.7	-24.94	140.7	-29.53	23.09	6.357
-897	-89.7	-1.168	0.757	0.364	-111.2	-27.93	138.1	-29.65	22.34	7.218
-896	-89.6	-1.168	0.724	0.398	-105.7	-30.92	135.6	-29.77	21.6	8.08
-895	-89.5	-1.168	0.693	0.429	-100.2	-33.91	133	-29.88	20.85	8.945
-894	-89.4	-1.168	0.659	0.463	-94.74	-36.9	130.4	-30	20.1	9.806
-893	-89.3	-1.168	0.628	0.494	-89.24	-39.88	127.9	-30.11	19.36	10.67
-892	-89.2	-1.168	0.595	0.527	-83.75	-42.87	125.3	-30.23	18.61	11.53
-891	-89.1	-1.168	0.564	0.558	-78.24	-45.87	122.7	-30.34	17.86	12.39
-890	-89	-1.168	0.53	0.592	-72.75	-48.85	120.1	-30.46	17.12	13.26
-889	-88.9	-1.168	0.499	0.623	-67.25	-51.84	117.6	-30.58	16.37	14.12
-888	-88.8	-1.168	0.465	0.656	-61.75	-54.82	115	-30.69	15.63	14.98
-887	-88.7	-1.168	0.435	0.687	-56.25	-57.82	112.4	-30.81	14.88	15.84
-886	-88.6	-1.168	0.401	0.721	-50.75	-60.8	109.9	-30.93	14.13	16.7
-885	-88.5	-1.168	0.37	0.752	-45.25	-63.79	107.3	-31.04	13.39	17.57
-884	-88.4	-1.168	0.336	0.758	-39.76	-66.78	104.7	-30.98	12.58	18.3
-883	-88.3	-1.142	0.303	0.797	-34.14	-69.49	101.8	-30.55	11.68	18.79
-882	-88.2	-1.061	0.261	0.755	-28.3	-71.61	98.07	-30.13	10.76	19.27
-881	-88.1	-0.979	0.221	0.715	-22.45	-73.75	94.37	-29.7	9.845	19.76
-880	-88	-0.9	0.182	0.676	-16.61	-75.88	90.67	-29.28	8.942	20.24

APPENDIX II

CURRET TRANSFORMER MODELLING

We have decided to use 3I0, which is extracted from the current waveforms, to predict the presence of single phase fault. The CT and A/D convertors errors will affect such a decision and therefore we need to model the current transformers. So, the objective of this section is to eliminate the errors of the CTs (12500:1) through modelling.

AII. 1. SOURCE OF ERRORS

There are two kinds of errors. The inherent ratio and phase errors exist in the CT of each phase (phases R, S, T) and the ratio difference error which affects the summation of the three CTs currents.

AII. 2. CT TRANSIENT MODEL

The objective in here is to find out the primary current of each CT from its secondary current. Saturation of the electromagnetic core is the major factor that influences the current transformer transient response. It is caused by non-linear nature of the electromagnetic core of the current transformer. Saturation can lead to sever signal distortions in the current transformer output, if the primary current is too high. It can be represented using V-I characteristic of the core. The V-I characteristic of our CT tested by the manufacturer is shown in Figure AII.1. The errors measured by the manufacture are also shown in this figure. The characteristic presents dependency of exciting voltage V to the exciting current Ie. This dependence is actually the input-output characteristics of a non-linear inductor that can be used to model the electromagnetic core. The model of the CT with its core is shown in Figure AII.2.

The following equations are used to provide the block diagram transfer function of the model shown in figure AII.3:

$$I_e = I_{e1_x} + I\mathbf{e}_2$$

$$Ip = Is + I\mathbf{e}_,$$

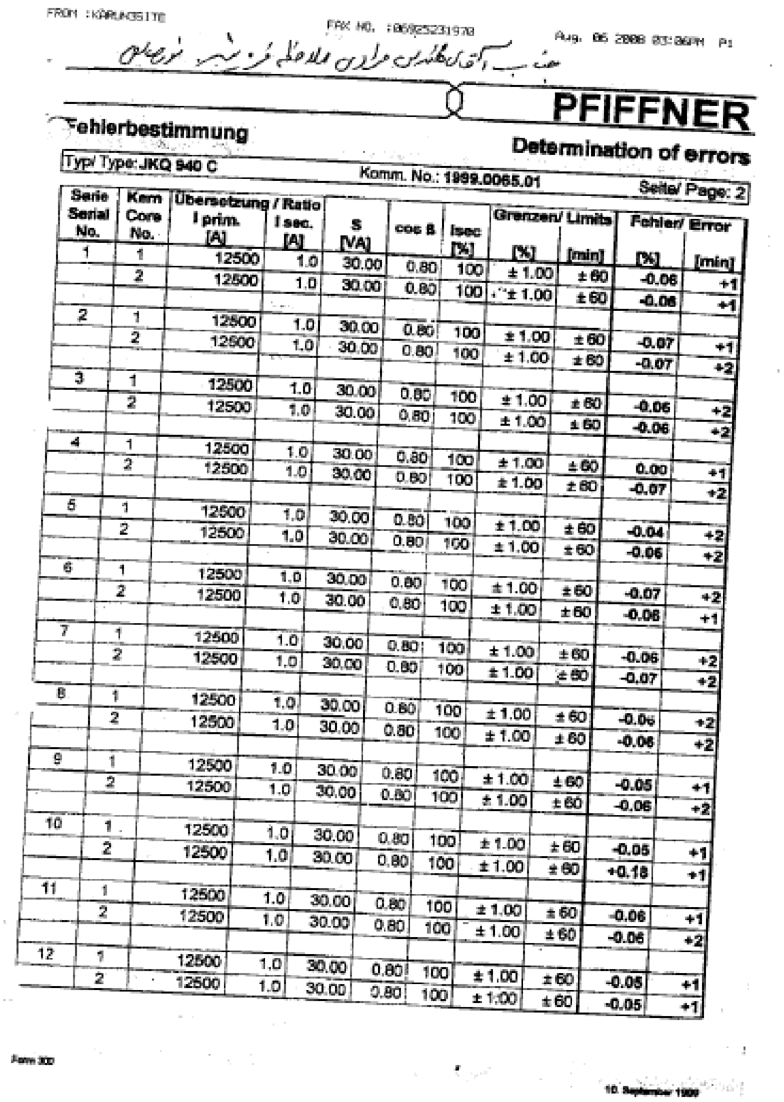
$$V = RmI_{e1_x} = dLmI_{e2_x} / dt = I_{e2_x} dLm / dt + LmdI_{e2_x} / dt$$

$$dLm / dt = dLm / dV * dV / dt$$

$$V = (Rb + Rc)Is + (Lb + Lc)dIs / dt_{y'}$$

From these equations and knowing the values of the Is(t), the Ie(t) and the Ip(t) can be found. Block diagram transfer function shown in Figure AII. 3. Is used to find the primary current. The Lm and d Lm / dV are read from the V-I characteristics of the CT.

Figure AII.1 Manufacturer characteristics for 12500:1 current transformer



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PFIFFNER

Fehlerbestimmung **Determination of errors**

Typ/ Type: **JKQ 940 C**

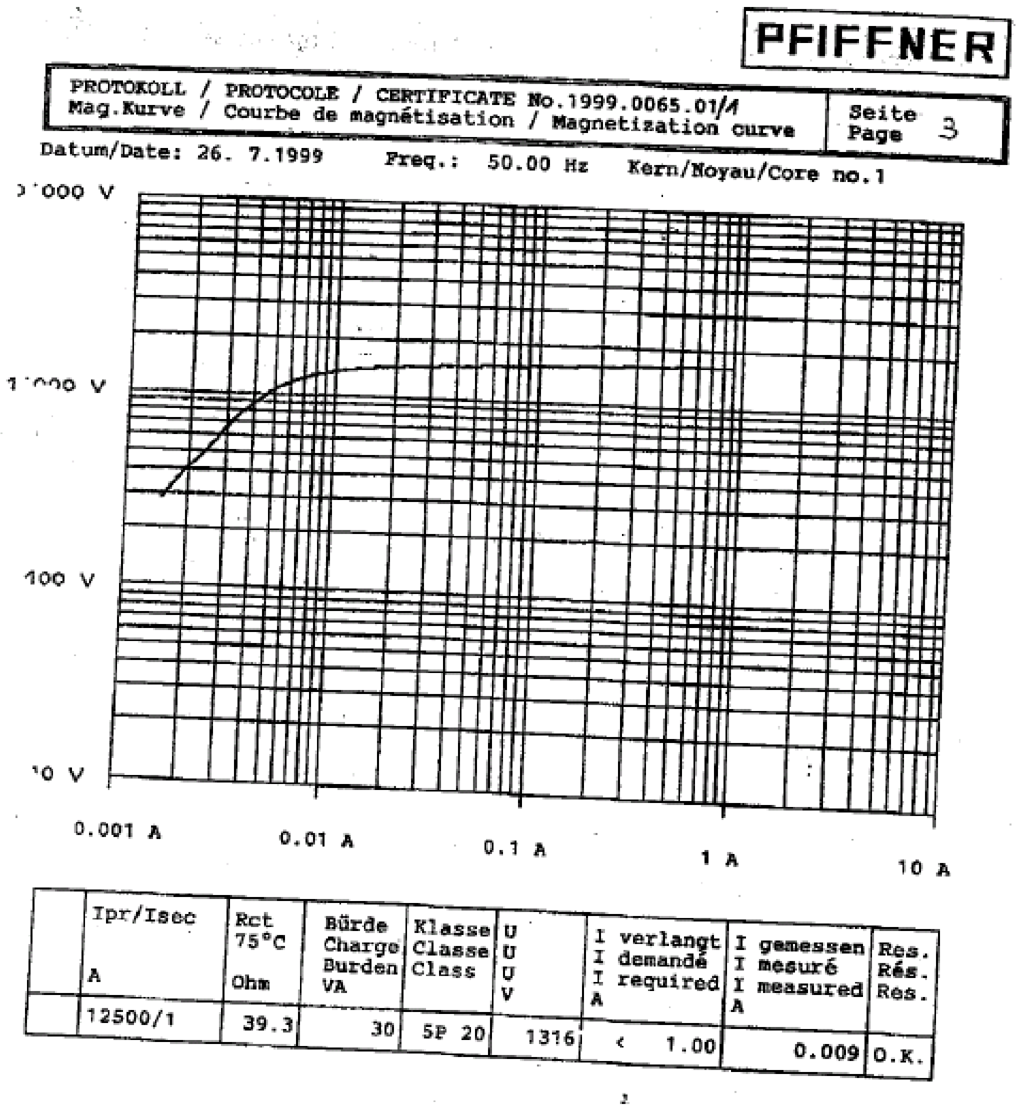
Komm. No.: **1999.0065.01**

Seite/ Page: 2

Serie Serial No.	Kern Core No.	Übersetzung / Ratio I prim. [A]	I sec. [A]	S [VA]	cos ß	Isec [%]	Grenzen/ Limits [%]	[min]	Fehler/ Error [%]	[min]
1	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+1
2	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.07	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.07	+2
3	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
4	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	0.00	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.07	+2
5	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.04	+2
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
6	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.07	+2
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.08	+1
7	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.07	+2
8	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
9	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.05	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
10	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.05	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	+0.18	+1
11	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.06	+2
12	1	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.05	+1
	2	12500	1.0	30.00	0.80	100	± 1.00	± 60	-0.05	+1

Form 300

10. September 1999



PFIFFNER

PROTOKOLL / PROTOCOLE / CERTIFICATE No.1999.0065.01/1
Mag.Kurve / Courbe de magnétisation / Magnetization curve

Seite
Page 3

Datum/Date: 26. 7.1999 Freq.: 50.00 Hz Kern/Noyau/Core no.1

	Ipr/Isec A	Rct 75°C Ohm	Bürde Charge Burden VA	Klasse Classe Class	U U U V	I verlangt I demandé I required A	I gemessen I mesuré I measured A	Res. Rés. Res.
	12500/1	39.3	30	5P 20	1316	< 1.00	0.009	O.K.

Figure AII.2 CT model

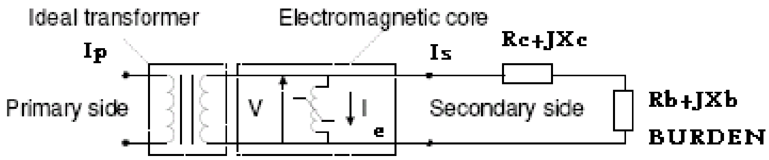
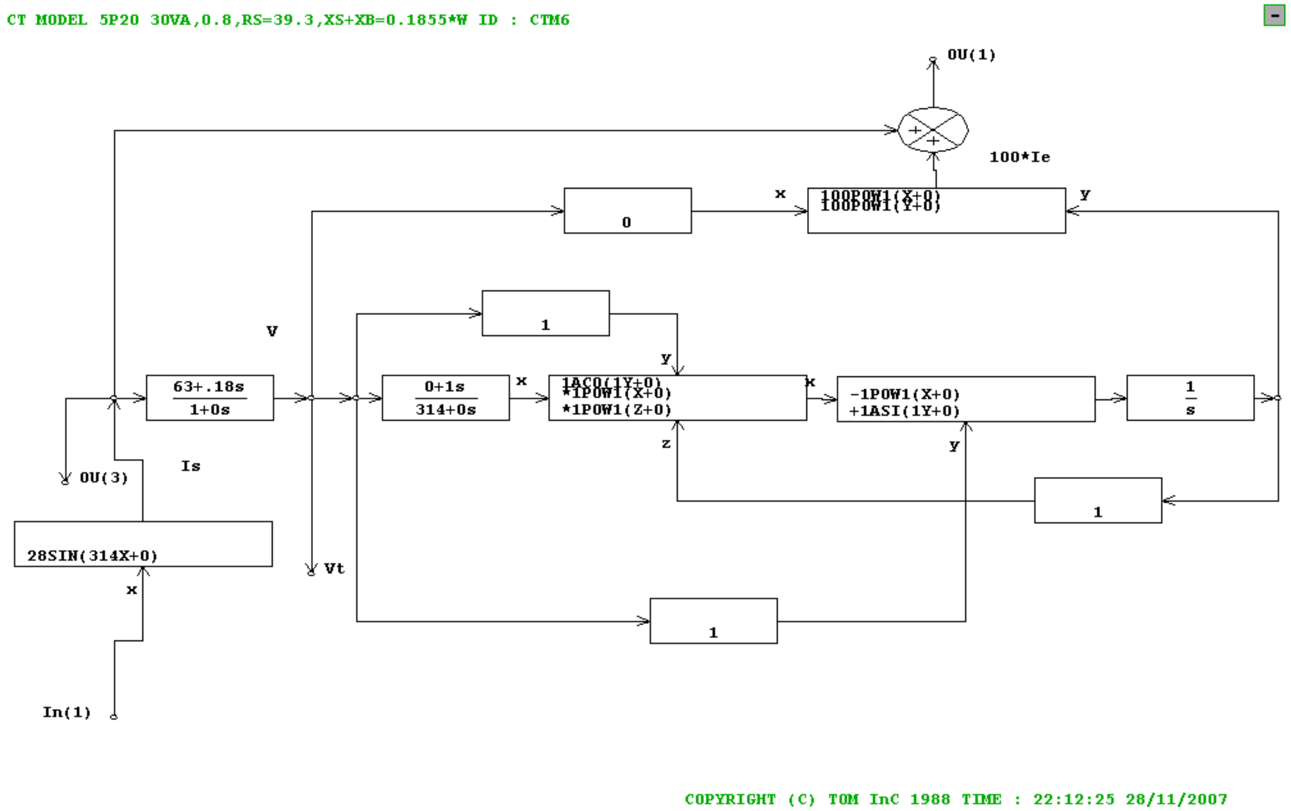


Figure AII.3 the block diagram transfer function model



AII. 2.1. TESTING THE CT MODEL

The CT model is checked, for the situation tested by the manufacturer (30VA, 0.8 power factor burdens). The errors obtained are listed in table AII.1 shows the validation of the model. Figure AII.4 shows the transient response of the CT error when applying 20 times of the nominal current.

Table AII.1

CT error when applying 1.41sin(wt) = 0.07 = 0.06%
CT error when applying 28.2sin(wt) = 141.6 = 5%

AII. 2.2. USING THE CT MODEL TO OBTAIN THE PRIMARY CURRENTS

The actual burden of our CT is measured to be:

0.44 V in 0.771 A.

The CT model has changed for the new burdens; a typical reactance is used for the burden (it has no much effect in the result). The measured currents as represented in Table I.1 are injected to the CT model. In order to initialize the model, a sinusoidal current for a period of about 0.2 sec as the delay time was injected to the model before injecting the measured values. The delay time is configured to match to the initial value of the measured current.

Figure AII.5 shows the block diagram transfer function form of the model. The measured currents in Table I.1 were injected to the model as described in the above, and the outputs are represented in Table AII.2. For the definition of the variables, please refer to appendix I.

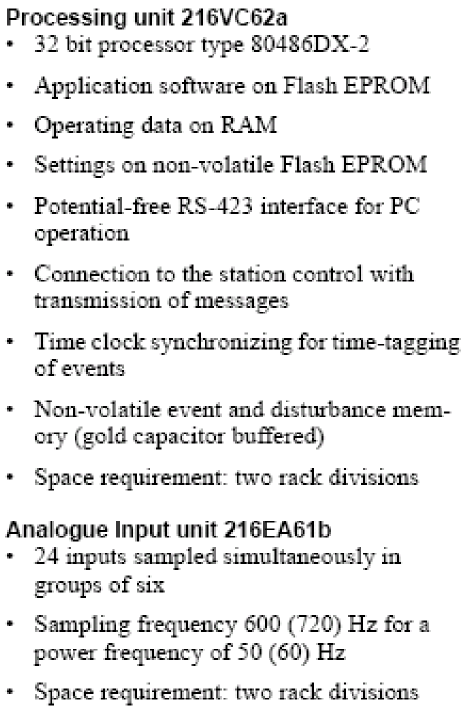
AII. 3. CTs difference error

The zero sequence current has been calculated using the residual currents from three current transformers (one per phase). This is not ideal since high phase currents may cause unequal saturation of the current transformers or unequal ratio errors and produce a false residual current calculated value. In our case the zero sequence current of the unfaulted system is important and during this region of the operation the current is in normal mode before two phases fault. To be insuring about this, a test has been made for unit 8 and the currents are recorded in a normal mode of operation. The CT modelling discussed above has applied and it has been found that the zero sequence currents are in the order of 12A, which is the error of recording digit numbers. During the meeting of 6th of Jan. 2008, one of the respected audience (Dr. Akbari) subject that there are another source of error and that would be A/D convertor digitizer error. With regard to his comments the following section treated in the revision D1 of this document is provided.

AII. 4. A/D convertor error

The following are selected from REG216 manual.

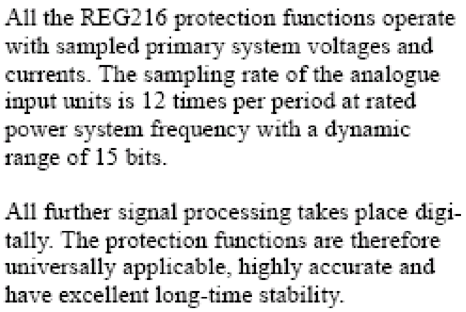
a)



Processing unit 216VC62a
- 32 bit processor type 80486DX-2
- Application software on Flash EPROM
- Operating data on RAM
- Settings on non-volatile Flash EPROM
- Potential-free RS-423 interface for PC operation
- Connection to the station control with transmission of messages
- Time clock synchronizing for time-tagging of events
- Non-volatile event and disturbance memory (gold capacitor buffered)
- Space requirement: two rack divisions

Analogue Input unit 216EA61b
- 24 inputs sampled simultaneously in groups of six
- Sampling frequency 600 (720) Hz for a power frequency of 50 (60) Hz
- Space requirement: two rack divisions

b)

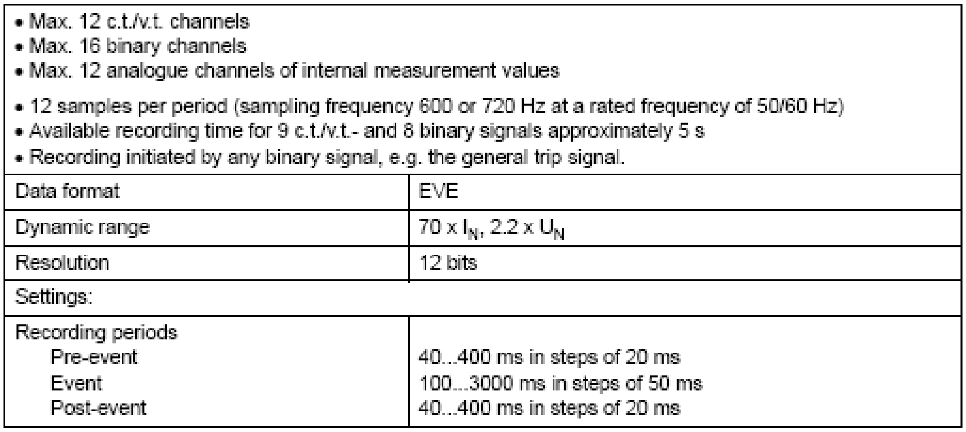


All the REG216 protection functions operate with sampled primary system voltages and currents. The sampling rate of the analogue input units is 12 times per period at rated power system frequency with a dynamic range of 15 bits.

All further signal processing takes place digitally. The protection functions are therefore universally applicable, highly accurate and have excellent long-time stability.

c)

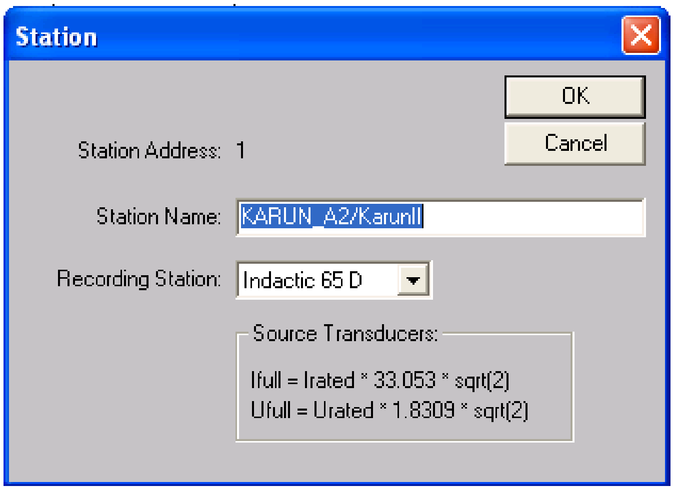
Table 35: Disturbance recorder



• Max. 12 c.t./v.t. channels • Max. 16 binary channels • Max. 12 analogue channels of internal measurement values • 12 samples per period (sampling frequency 600 or 720 Hz at a rated frequency of 50/60 Hz) • Available recording time for 9 c.t./v.t.- and 8 binary signals approximately 5 s • Recording initiated by any binary signal, e.g. the general trip signal.	
Data format	EVE
Dynamic range	70 x I_N, 2.2 x U_N
Resolution	12 bits
Settings:	
Recording periods Pre-event Event Post-event	 40...400 ms in steps of 20 ms 100...3000 ms in steps of 50 ms 40...400 ms in steps of 20 ms

The followings are selected from Win-Eve software station records,

d)



Station Address: 1

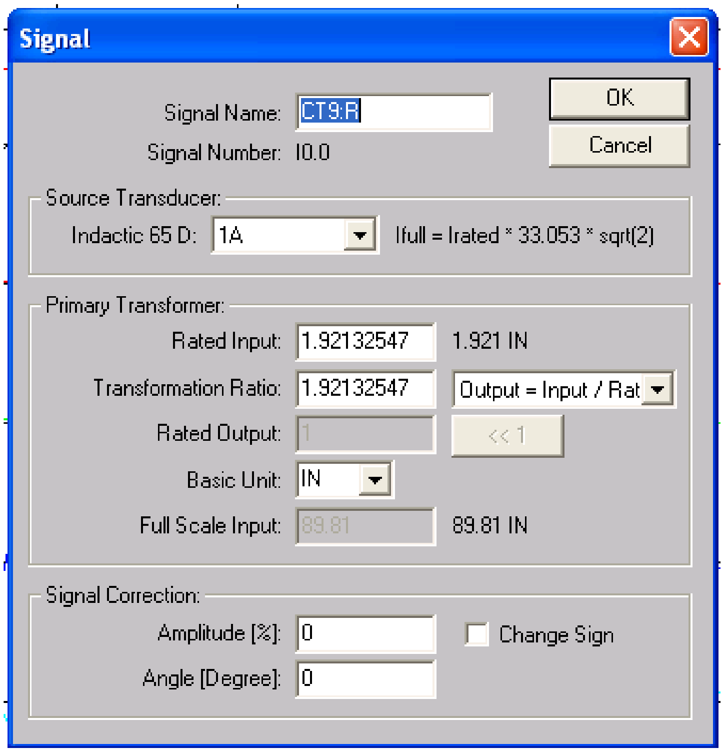
Station Name: KARUN_A2/KarunII

Recording Station: Indactic 65 D

Source Transducers:

Ifull = Irated * 33.053 * sqrt(2)
Ufull = Urated * 1.8309 * sqrt(2)

f)



Signal

Signal Name: CT9:R

Signal Number: I0.0

Source Transducer:

Indactic 65 D: 1A Ifull = Irated * 33.053 * sqrt(2)

Primary Transformer:

Rated Input: 1.92132547 1.921 IN

Transformation Ratio: 1.92132547 Output = Input / Rat

Rated Output: 1 << 1

Basic Unit: IN

Full Scale Input: 89.81 89.81 IN

Signal Correction:

Amplitude [%]: 0 ☐ Change Sign

Angle [Degree]: 0

According to the above, the full scale of the digital record is 89.91A, pick. If the recorder would use 15 bits this have enforce 89.81*2 / 32767 = 0.0055A error on secondary.

However, according to the manual (section c above) disturbance recorder uses just 12 bits from the 15 bits available! for the recording purposes and this will bring :

89.81*2 / 4095 = 0.04386A error on secondary. The error is too high and can eliminate the CTs and any other source of errors!! Another drawback of this error is in the Win-Eve software from ABB that is how it reports its values with three decimal digits if the errors are in the order of 0.044IN! Finally the setting of full scale at 89.81 is selected too high.

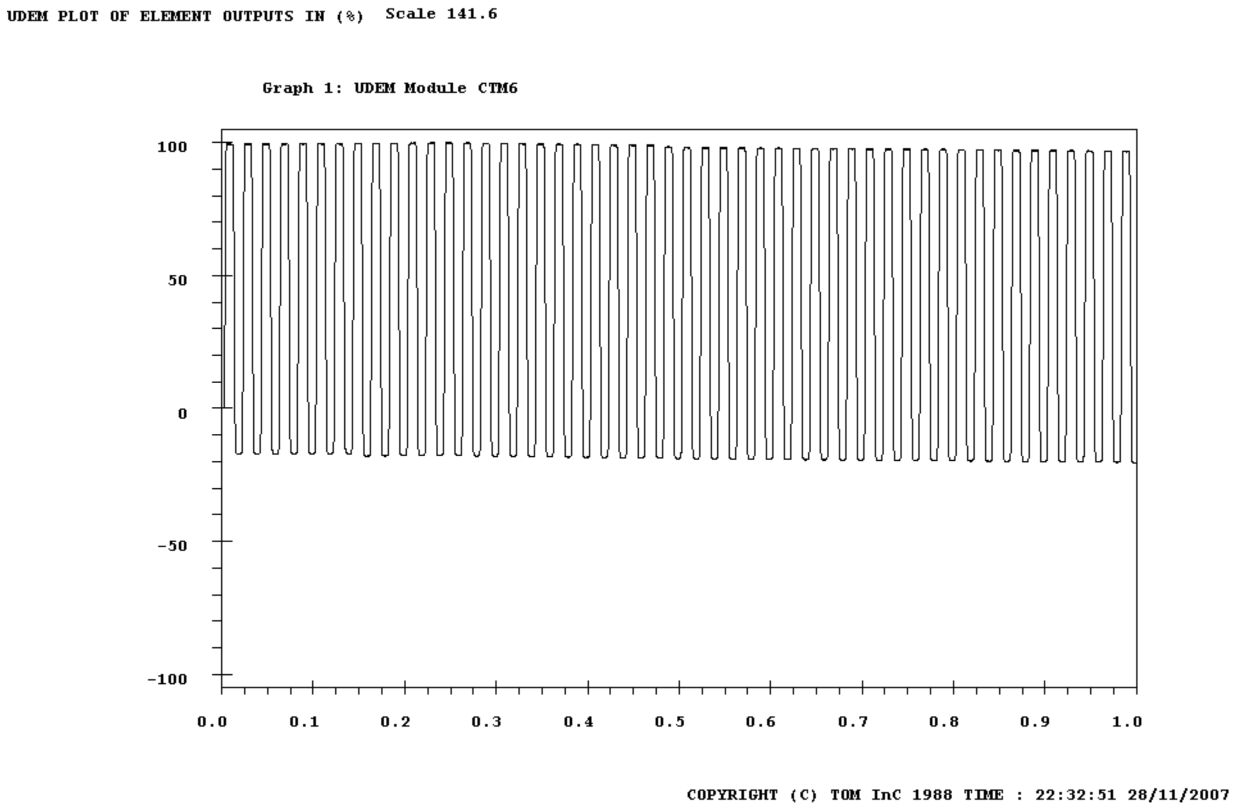
The above discussion brings the sub-conclusion of section AII.3 .of revision D0 of this report ("Therefore, we reached to the conclusion that no difference error is presented in our calculations, at least before two phases fault"), under question and this may not be true as Dr. Akbari suggested. However, it also show that it might be existed a single phase fault that its current magnitude values are lost in the errors that are just mentioned. From the waveforms we can reach that the measurements are taken place in the times: -98.1 -96.5 -94.9 -93.3 -91.7 -90.1 -88.5. Omitting the maximum assumed A/D convertor errors in these regions will change Table AI.1 as that is shown in table AII.3. This indicates that there would be some differences, which emphasis that the 3I0 has been lost inside the error margins; otherwise the exact zero would be expected.

The discussion in this section must be further followed by a group of digital computing experts, which opens the actual record files in 12 digit format and further helps to find the actual situation.

However, the process discussed in the sequence of the events (section 5 of this report) is still valid for damages occurred in unit 7 for the following reasons:

1- There is no doubt that the primary two phase fault is between slot 326 and 327 as shown in Appendix III.
2- This fault has occurred because of overvoltage
3- The overvoltage must be due to single phase fault with the arcing ground phenomenon, as 64GB relay announced it before differential relay announcements. A/D errors cannot omit this possibility.
4- Ferroresonace must had been occurred, because of the damage occurred in PT3 as shown in Appendix V.

Figure AII.4 Checking CT error in 20 times of nominal current, 100*Ie



UDEM PLOT OF ELEMENT OUTPUTS IN (%) Scale 141.6

Graph 1: UDEM Module CTM6

COPYRIGHT (C) TOM InC 1988 TIME : 22:32:51 28/11/2007

Figure AII.5 Block diagram transfer function of the CT model, used to find the primary currents

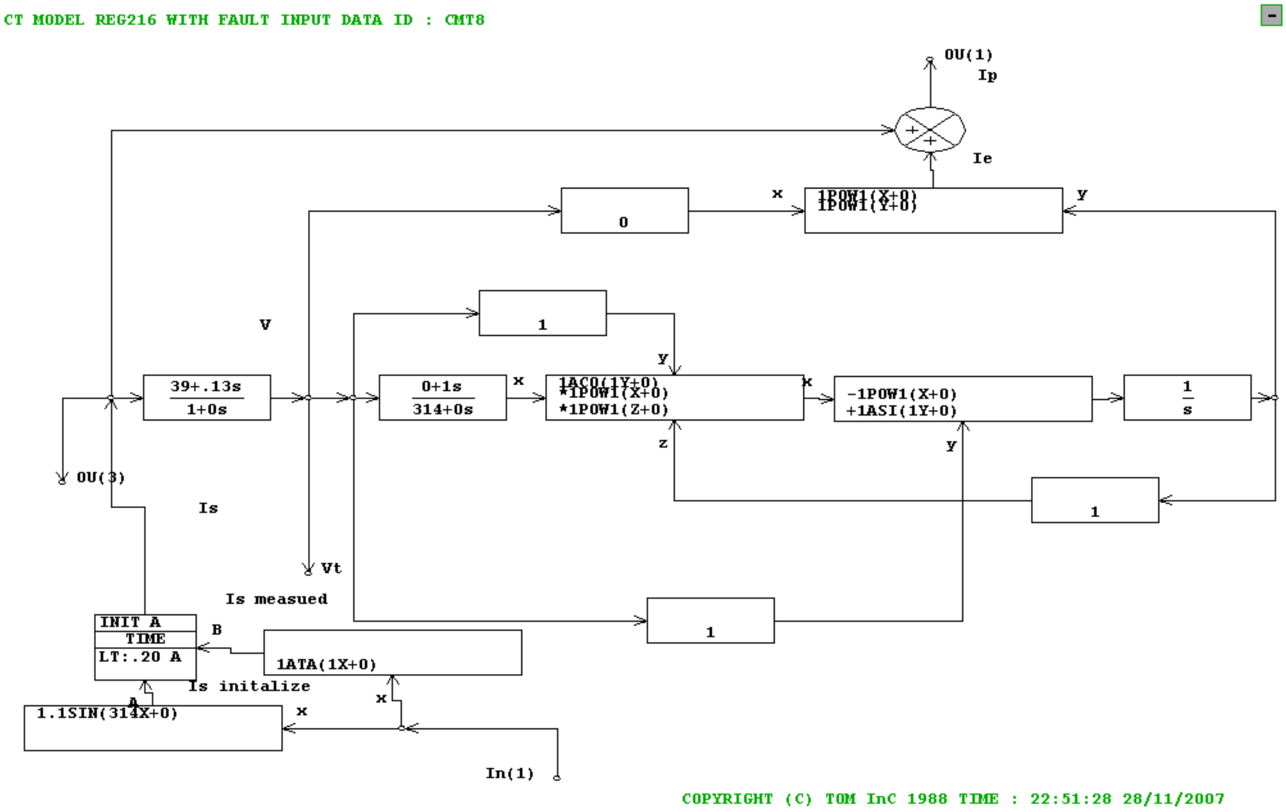


Table AII.2 instantaneous values of the measured data, CT model used to omit the errors

CURSOR	TIME	Ir	Is	It	Ir+Is+It	Vrs	Vst	Vtr	Vrs+Vst+Vtr	time (msec)	Vrn (p.u.)	Vsn(p.u.)	Vtn(p.u.)
-984	-98.4	1.123	-0.314	-0.808	0.001	63.02	93.68	-158.7	-2	0	1.164	0.161	-1.325
-983	-98.3	1.117	-0.303	-0.813	0.001	61.4	94.69	-158.1	-2.01	0.1	1.152	0.175	-1.327
-982	-98.2	1.100	-0.266	-0.830	0.005	56.51	97.76	-156.2	-1.93	0.2	1.116	0.217	-1.333
-981	-98.1	1.081	-0.227	-0.850	0.004	51.61	100.8	-154.3	-1.89	0.3	1.081	0.258	-1.339
-980	-98	1.061	-0.190	-0.870	0.001	46.72	103.9	-152.5	-1.88	0.4	1.046	0.300	-1.346
-979	-97.9	1.041	-0.151	-0.889	0.001	41.84	107	-150.6	-1.76	0.5	1.010	0.342	-1.352
-978	-97.8	1.024	-0.115	-0.906	0.004	36.95	110	-148.7	-1.75	0.6	0.974	0.383	-1.358
-977	-97.7	1.005	-0.075	-0.926	0.005	32.06	113.1	-146.8	-1.64	0.7	0.939	0.425	-1.364
-976	-97.6	0.985	-0.039	-0.945	0.001	27.17	116.2	-144.9	-1.53	0.8	0.903	0.467	-1.370
-975	-97.5	0.968	-0.002	-0.962	0.005	22.29	119.2	-143.1	-1.61	0.9	0.868	0.509	-1.377
-974	-97.4	0.948	0.036	-0.982	0.002	17.4	122.3	-141.2	-1.5	1	0.832	0.551	-1.383
-973	-97.3	0.929	0.072	-1.002	0.000	12.5	125.4	-139.3	-1.4	1.1	0.797	0.593	-1.389
-972	-97.2	0.909	0.112	-1.022	0.000	7.612	128.5	-137.4	-1.288	1.2	0.761	0.634	-1.396
-971	-97.1	0.892	0.148	-1.038	0.002	2.721	131.5	-135.5	-1.279	1.3	0.725	0.676	-1.401
-970	-97	0.872	0.188	-1.058	0.002	-2.16	134.6	-133.7	-1.26	1.4	0.690	0.718	-1.408
-969	-96.9	0.853	0.224	-1.078	-0.001	-7.051	137.7	-131.8	-1.151	1.5	0.655	0.760	-1.415
-968	-96.8	0.833	0.263	-1.097	-0.001	-11.94	140.7	-129.9	-1.14	1.6	0.619	0.801	-1.420
-967	-96.7	0.816	0.300	-1.114	0.002	-16.83	143.8	-128	-1.03	1.7	0.583	0.843	-1.427
-966	-96.6	0.788	0.334	-1.123	0.000	-21.51	145.3	-124.8	-1.01	1.8	0.542	0.876	-1.418
-965	-96.5	0.755	0.362	-1.123	-0.006	-26.1	146	-121	-1.1	1.9	0.498	0.903	-1.401
-964	-96.4	0.724	0.392	-1.123	-0.007	-30.68	146.7	-117.2	-1.18	2	0.454	0.931	-1.385
-963	-96.3	0.690	0.421	-1.123	-0.012	-35.27	147.4	-113.3	-1.17	2.1	0.410	0.959	-1.368
-962	-96.2	0.659	0.451	-1.123	-0.013	-39.85	148.2	-109.5	-1.15	2.2	0.366	0.987	-1.353
-961	-96.1	0.625	0.479	-1.123	-0.019	-44.44	148.9	-105.7	-1.24	2.3	0.322	1.015	-1.336
-960	-96	0.595	0.510	-1.123	-0.017	-49.02	149.6	-101.9	-1.32	2.4	0.278	1.042	-1.320
-959	-95.9	0.561	0.538	-1.123	-0.024	-53.6	150.3	-98.02	-1.32	2.5	0.233	1.070	-1.303
-958	-95.8	0.530	0.569	-1.123	-0.023	-58.19	151	-94.19	-1.38	2.6	0.189	1.098	-1.287
-957	-95.7	0.496	0.600	-1.123	-0.027	-62.77	151.7	-90.35	-1.42	2.7	0.145	1.126	-1.270
-956	-95.6	0.465	0.628	-1.123	-0.029	-67.36	152.4	-86.52	-1.48	2.8	0.101	1.153	-1.254
-955	-95.5	0.432	0.659	-1.123	-0.032	-71.94	153.1	-82.69	-1.53	2.9	0.056	1.181	-1.238
-954	-95.4	0.401	0.687	-1.123	-0.035	-76.53	153.8	-78.86	-1.59	3	0.012	1.209	-1.221
-953	-95.3	0.367	0.718	-1.123	-0.038	-81.11	154.6	-75.02	-1.53	3.1	-0.032	1.237	-1.205
-952	-95.2	0.336	0.746	-1.123	-0.041	-85.7	155.3	-71.19	-1.59	3.2	-0.076	1.265	-1.189

-951	-95.1	0.303	0.777	-1.123	-0.043	-90.28	156	-67.36	-1.64	3.3	-0.120	1.293	-1.172
-950	-95	0.272	0.805	-1.123	-0.046	-94.85	156.7	-63.54	-1.69	3.4	-0.164	1.320	-1.156
-949	-94.9	0.232	0.827	-1.109	-0.049	-97.97	154.8	-58.57	-1.74	3.5	-0.207	1.327	-1.120
-948	-94.8	0.196	0.850	-1.092	-0.046	-101.1	153	-53.62	-1.72	3.6	-0.249	1.334	-1.084
-947	-94.7	0.157	0.872	-1.075	-0.046	-104.2	151.1	-48.65	-1.75	3.7	-0.292	1.340	-1.048
-946	-94.6	0.120	0.892	-1.058	-0.046	-107.3	149.3	-43.69	-1.69	3.8	-0.334	1.347	-1.013
-945	-94.5	0.081	0.914	-1.044	-0.049	-110.4	147.4	-38.73	-1.73	3.9	-0.376	1.353	-0.977
-944	-94.4	0.044	0.937	-1.027	-0.046	-113.5	145.5	-33.77	-1.77	4	-0.418	1.359	-0.941
-943	-94.3	0.005	0.957	-1.010	-0.048	-116.6	143.7	-28.81	-1.71	4.1	-0.461	1.366	-0.905
-942	-94.2	-0.030	0.979	-0.993	-0.044	-119.7	141.8	-23.85	-1.75	4.2	-0.503	1.373	-0.869
-941	-94.1	-0.067	1.002	-0.979	-0.044	-122.8	140	-18.89	-1.69	4.3	-0.545	1.379	-0.834
-940	-94	-0.106	1.022	-0.962	-0.046	-126	138.1	-13.93	-1.83	4.4	-0.588	1.386	-0.798
-939	-93.9	-0.143	1.044	-0.945	-0.044	-129.1	136.2	-8.968	-1.868	4.5	-0.631	1.392	-0.762
-938	-93.8	-0.182	1.066	-0.929	-0.045	-132.2	134.4	-4.013	-1.813	4.6	-0.673	1.399	-0.726
-937	-93.7	-0.218	1.086	-0.914	-0.046	-135.3	132.5	0.952	-1.848	4.7	-0.715	1.406	-0.690
-936	-93.6	-0.258	1.109	-0.898	-0.047	-138.4	130.7	5.908	-1.792	4.8	-0.757	1.412	-0.655
-935	-93.5	-0.294	1.131	-0.881	-0.044	-141.5	128.8	10.87	-1.83	4.9	-0.800	1.419	-0.619
-934	-93.4	-0.334	1.151	-0.864	-0.047	-144.6	126.9	15.83	-1.87	5	-0.842	1.425	-0.583
-933	-93.3	-0.367	1.168	-0.844	-0.043	-146.9	124.4	20.65	-1.85	5.1	-0.879	1.424	-0.545
-932	-93.2	-0.398	1.168	-0.811	-0.041	-147.7	120.6	25.17	-1.93	5.2	-0.907	1.408	-0.501
-931	-93.1	-0.426	1.168	-0.780	-0.038	-148.4	116.8	29.69	-1.91	5.3	-0.935	1.392	-0.457
-930	-93	-0.457	1.168	-0.746	-0.035	-149.1	113	34.21	-1.89	5.4	-0.962	1.376	-0.414
-929	-92.9	-0.485	1.168	-0.715	-0.032	-149.9	109.2	38.74	-1.96	5.5	-0.990	1.360	-0.370
-928	-92.8	-0.516	1.168	-0.682	-0.030	-150.6	105.4	43.26	-1.94	5.6	-1.018	1.344	-0.326
-927	-92.7	-0.544	1.168	-0.651	-0.027	-151.3	101.6	47.78	-1.92	5.7	-1.045	1.327	-0.282
-926	-92.6	-0.575	1.168	-0.617	-0.024	-152.1	97.83	52.3	-1.97	5.8	-1.073	1.312	-0.239
-925	-92.5	-0.603	1.168	-0.586	-0.021	-152.8	94.03	56.82	-1.95	5.9	-1.100	1.296	-0.195
-924	-92.4	-0.634	1.168	-0.552	-0.018	-153.5	90.22	61.35	-1.93	6	-1.128	1.279	-0.152
-923	-92.3	-0.665	1.168	-0.519	-0.016	-154.3	86.42	65.88	-2	6.1	-1.156	1.263	-0.108
-922	-92.2	-0.693	1.168	-0.488	-0.013	-155	82.61	70.4	-1.99	6.2	-1.183	1.247	-0.064
-921	-92.1	-0.724	1.168	-0.454	-0.010	-155.7	78.81	74.92	-1.97	6.3	-1.210	1.231	-0.020
-920	-92	-0.752	1.168	-0.423	-0.007	-156.5	75.01	79.44	-2.05	6.4	-1.238	1.215	0.023
-919	-91.9	-0.783	1.168	-0.390	-0.005	-157.2	71.21	83.97	-2.02	6.5	-1.266	1.199	0.067
-918	-91.8	-0.811	1.168	-0.359	-0.002	-157.9	67.41	88.49	-2	6.6	-1.293	1.183	0.111
-917	-91.7	-0.842	1.168	-0.325	0.001	-158.6	63.61	93.01	-1.98	6.7	-1.321	1.166	0.154
-916	-91.6	-0.864	1.156	-0.291	0.001	-157.7	59.09	96.57	-2.04	6.8	-1.335	1.138	0.197
-915	-91.5	-0.884	1.137	-0.258	-0.005	-155.8	54.22	99.65	-1.93	6.9	-1.341	1.102	0.238
-914	-91.4	-0.900	1.120	-0.221	-0.001	-153.9	49.34	102.7	-1.86	7	-1.347	1.067	0.280

-913	-91.3	-0.920	1.100	-0.188	-0.008	-152	44.46	105.8	-1.74	7.1	-1.353	1.031	0.322
-912	-91.2	-0.940	1.081	-0.151	-0.010	-150.2	39.58	108.9	-1.72	7.2	-1.360	0.996	0.364
-911	-91.1	-0.959	1.061	-0.117	-0.015	-148.3	34.7	112	-1.6	7.3	-1.366	0.961	0.406
-910	-91	-0.976	1.044	-0.081	-0.013	-146.4	29.82	115.1	-1.48	7.4	-1.373	0.925	0.448
-909	-90.9	-0.996	1.024	-0.047	-0.019	-144.6	24.94	118.1	-1.56	7.5	-1.379	0.890	0.489
-908	-90.8	-1.016	1.005	-0.011	-0.022	-142.7	20.06	121.2	-1.44	7.6	-1.385	0.854	0.531
-907	-90.7	-1.033	0.987	0.022	-0.024	-140.8	15.18	124.3	-1.32	7.7	-1.391	0.819	0.573
-906	-90.6	-1.052	0.968	0.058	-0.026	-139	10.3	127.4	-1.3	7.8	-1.398	0.784	0.615
-905	-90.5	-1.072	0.948	0.092	-0.031	-137.1	5.431	130.4	-1.269	7.9	-1.404	0.748	0.656
-904	-90.4	-1.092	0.929	0.129	-0.034	-135.2	0.55	133.5	-1.15	8	-1.410	0.713	0.698
-903	-90.3	-1.109	0.912	0.162	-0.035	-133.3	-4.33	136.6	-1.03	8.1	-1.417	0.677	0.740
-902	-90.2	-1.128	0.892	0.199	-0.037	-131.5	-9.21	139.7	-1.011	8.2	-1.423	0.642	0.782
-901	-90.1	-1.148	0.872	0.232	-0.044	-129.6	-14.1	142.8	-0.89	8.3	-1.430	0.606	0.823
-900	-90	-1.165	0.856	0.266	-0.043	-127.7	-19	145.8	-0.86	8.4	-1.436	0.571	0.865
-899	-89.9	-1.168	0.822	0.300	-0.046	-122.2	-22	143.3	-0.86	8.5	-1.394	0.526	0.867
-898	-89.8	-1.168	0.788	0.334	-0.046	-116.7	-24.9	140.7	-0.94	8.6	-1.351	0.482	0.869
-897	-89.7	-1.168	0.757	0.364	-0.047	-111.2	-27.9	138.1	-1.03	8.7	-1.308	0.437	0.871
-896	-89.6	-1.168	0.724	0.398	-0.046	-105.7	-30.9	135.6	-1.02	8.8	-1.266	0.392	0.874
-895	-89.5	-1.168	0.693	0.429	-0.046	-100.2	-33.9	133	-1.11	8.9	-1.224	0.348	0.876
-894	-89.4	-1.168	0.659	0.463	-0.046	-94.74	-36.9	130.4	-1.24	9	-1.182	0.304	0.878
-893	-89.3	-1.168	0.628	0.494	-0.046	-89.24	-39.9	127.9	-1.22	9.1	-1.140	0.259	0.881
-892	-89.2	-1.168	0.595	0.527	-0.046	-83.75	-42.9	125.3	-1.32	9.2	-1.097	0.215	0.883
-891	-89.1	-1.168	0.564	0.558	-0.046	-78.24	-45.9	122.7	-1.41	9.3	-1.055	0.170	0.885
-890	-89	-1.168	0.530	0.592	-0.046	-72.75	-48.9	120.1	-1.5	9.4	-1.012	0.125	0.887
-889	-88.9	-1.168	0.499	0.623	-0.046	-67.25	-51.8	117.6	-1.49	9.5	-0.970	0.081	0.889
-888	-88.8	-1.168	0.465	0.656	-0.047	-61.75	-54.8	115	-1.57	9.6	-0.928	0.036	0.891
-887	-88.7	-1.168	0.435	0.687	-0.046	-56.25	-57.8	112.4	-1.67	9.7	-0.885	-0.008	0.893
-886	-88.6	-1.168	0.401	0.721	-0.046	-50.75	-60.8	109.9	-1.65	9.8	-0.843	-0.053	0.896
-885	-88.5	-1.168	0.370	0.752	-0.046	-45.25	-63.8	107.3	-1.74	9.9	-0.801	-0.097	0.898
-884	-88.4	-1.168	0.336	0.758	-0.074	-39.76	-66.8	104.7	-1.84	10	-0.758	-0.142	0.900
-883	-88.3	-1.142	0.303	0.797	-0.042	-34.14	-69.5	101.8	-1.83	10.1	-0.714	-0.186	0.899
-882	-88.2	-1.061	0.261	0.755	-0.045	-28.3	-71.6	98.07	-1.84	10.2	-0.663	-0.227	0.891
-881	-88.1	-0.979	0.221	0.715	-0.043	-22.45	-73.8	94.37	-1.83	10.3	-0.613	-0.269	0.882
-880	-88	-0.900	0.182	0.676	-0.042	-16.61	-75.9	90.67	-1.82	10.4	-0.563	-0.311	0.874

Table AII.2 continuation in rows instantaneous values of the measured data, CT model used to omit the errors

Vn0(p.u.))	Pr	Qr	Sr	Ps	Qs	Ss	Pt	Qt	St	P-P0	Q	S	S0	P+S0*
0	148.59	108.87	184.21	-5.74	51.56	51.88	121.70	-52.67	132.61	264.55	107.77	285.66	0.00	264.55
0	146.41	109.46	182.80	-6.02	49.57	49.93	122.65	-51.63	133.08	263.04	107.39	284.12	0.00	263.04
0	139.72	111.29	178.62	-6.55	42.99	43.49	125.80	-48.51	134.83	258.97	105.77	279.74	0.00	258.97
0	132.92	112.77	174.31	-6.66	36.24	36.85	129.41	-45.37	137.13	255.66	103.64	275.87	0.00	255.66
0	126.22	114.08	170.14	-6.48	29.98	30.68	133.13	-42.04	139.61	252.87	102.03	272.68	0.00	252.87
0	119.63	115.27	166.13	-5.87	23.53	24.26	136.68	-38.47	141.99	250.43	100.34	269.78	0.00	250.43
0	113.52	116.57	162.72	-5.01	17.70	18.39	139.89	-34.63	144.11	248.40	99.644	267.64	0.00	248.40
0	107.34	117.63	159.25	-3.63	11.40	11.96	143.64	-30.71	146.88	247.35	98.324	266.18	0.00	247.35
0	101.21	118.45	155.81	-2.07	5.85	6.21	147.27	-26.56	149.64	246.41	97.749	265.09	0.00	246.41
0	95.61	119.42	152.98	-0.12	0.30	0.32	150.60	-22.18	152.23	246.09	97.538	264.72	0.00	246.09
0	89.79	119.99	149.87	2.25	-5.25	5.72	154.44	-17.67	155.45	246.48	97.064	264.90	0.00	246.48
0	84.22	120.57	147.07	4.85	-10.37	11.45	158.30	-12.96	158.83	247.37	97.242	265.80	0.00	247.37
0	78.72	120.89	144.26	8.08	-15.92	17.85	162.20	-8.05	162.40	248.99	96.927	267.19	0.00	248.99
0	73.63	121.40	141.99	11.37	-20.74	23.66	165.42	-2.92	165.45	250.42	97.737	268.82	0.00	250.42
0	68.50	121.48	139.46	15.34	-26.00	30.19	169.43	2.36	169.45	253.27	97.842	271.51	0.00	253.27
0	63.55	121.57	137.18	19.34	-30.54	36.15	173.41	7.86	173.58	256.30	98.891	274.72	0.00	256.30
0	58.68	121.31	134.76	23.95	-35.34	42.69	177.19	13.55	177.70	259.82	99.514	278.22	0.00	259.82
0	54.18	121.45	132.99	28.75	-39.73	49.04	180.73	19.39	181.77	263.66	101.12	282.39	0.00	263.66
0	48.61	118.51	128.09	33.24	-43.12	54.45	181.05	24.99	182.77	262.90	100.38	281.41	0.00	262.90
1	42.79	114.10	121.86	37.17	-45.32	58.61	178.98	30.32	181.53	258.94	99.101	277.25	0.63	259.56
1	37.41	109.94	116.13	41.49	-47.53	63.09	176.90	35.64	180.45	255.80	98.05	273.95	0.74	256.54
1	32.16	105.28	110.08	45.88	-49.35	67.38	174.75	40.97	179.49	252.80	96.903	270.73	1.31	254.10
1	27.42	101.10	104.75	50.60	-51.09	71.91	172.74	46.29	178.84	250.76	96.299	268.62	1.42	252.18
1	22.87	96.34	99.02	55.26	-52.38	76.14	170.67	51.63	178.30	248.79	95.582	266.52	2.11	250.90
1	18.79	92.15	94.05	60.44	-53.77	80.89	168.59	56.95	177.95	247.82	95.33	265.53	1.99	249.81
1	14.89	87.29	88.55	65.45	-54.56	85.21	166.46	62.27	177.73	246.80	95.002	264.45	2.67	249.47
1	11.40	82.86	83.64	71.02	-55.45	90.10	164.36	67.60	177.72	246.78	95.008	264.44	2.67	249.45
1	8.17	77.91	78.33	76.78	-56.09	95.08	162.26	72.92	177.89	247.21	94.741	264.74	3.02	250.23
1	5.32	73.38	73.57	82.35	-56.22	99.71	160.16	78.26	178.26	247.83	95.414	265.56	3.36	251.19
1	2.77	68.49	68.54	88.49	-56.38	104.92	158.06	83.58	178.80	249.32	95.682	267.05	3.59	252.91
1	0.56	63.87	63.87	94.42	-56.05	109.80	155.97	88.91	179.53	250.94	96.723	268.93	3.93	254.87
1	-1.34	58.76	58.78	100.98	-55.73	115.34	153.93	94.23	180.48	253.57	97.26	271.59	4.27	257.84
1	-2.91	54.05	54.12	107.27	-54.95	120.53	151.83	99.56	181.57	256.19	98.662	274.53	4.61	260.80
1	-4.15	48.96	49.14	114.18	-54.15	126.37	149.73	104.89	182.81	259.76	99.696	278.24	4.84	264.60
1	-5.09	44.16	44.45	120.83	-52.92	131.91	147.64	110.20	184.23	263.38	101.43	282.23	5.18	268.56

1	-5.47	37.22	37.62	124.73	-50.12	134.42	141.25	112.40	180.52	260.52	99.502	278.87	5.63	266.15
1	-5.57	31.08	31.58	128.88	-47.16	137.23	134.69	114.22	176.60	258.00	98.142	276.04	5.18	263.18
1	-5.22	24.60	25.15	132.83	-43.89	139.90	128.18	115.89	172.80	255.80	96.593	273.43	5.18	260.98
1	-4.57	18.59	19.15	136.57	-40.32	142.40	121.89	117.45	169.27	253.89	95.717	271.34	5.18	259.07
1	-3.48	12.41	12.89	140.60	-36.63	145.29	116.00	119.24	166.36	253.12	95.023	270.37	5.52	258.64
1	-2.11	6.68	7.00	144.81	-32.74	148.46	109.91	120.59	163.16	252.60	94.533	269.71	5.18	257.78
1	-0.28	0.80	0.85	148.64	-28.53	151.35	104.01	121.84	160.20	252.37	94.108	269.35	5.41	257.78
1	1.70	-4.35	4.67	152.76	-24.16	154.66	98.20	122.97	157.37	252.65	94.465	269.73	4.95	257.60
1	4.13	-9.65	10.50	157.13	-19.58	158.34	92.86	124.38	155.22	254.12	95.142	271.35	4.95	259.07
1	7.07	-15.09	16.67	161.06	-14.73	161.73	87.31	125.40	152.80	255.43	95.58	272.73	5.18	260.61
1	10.23	-20.10	22.55	165.27	-9.69	165.56	81.89	126.22	150.46	257.40	96.431	274.87	4.95	262.35
1	13.90	-25.26	28.83	169.58	-4.43	169.64	76.76	127.06	148.45	260.25	97.379	277.87	5.07	265.31
1	17.70	-29.84	34.69	173.54	1.07	173.54	71.78	127.94	146.70	263.02	99.177	281.10	5.18	268.20
1	22.20	-34.84	41.31	178.08	6.78	178.21	66.90	128.58	144.95	267.17	100.52	285.46	5.29	272.47
1	26.71	-39.13	47.38	182.42	12.72	182.86	62.02	128.98	143.11	271.16	102.57	289.91	4.95	276.11
1	31.96	-43.81	54.22	186.47	18.85	187.42	57.29	129.26	141.39	275.72	104.31	294.79	5.29	281.01
1	36.67	-47.19	59.77	189.09	24.96	190.73	52.28	128.27	138.52	278.04	106.04	297.57	4.84	282.87
1	41.04	-49.62	64.39	187.00	30.42	189.46	46.20	123.93	132.26	274.24	104.73	293.56	4.61	278.85
1	45.25	-51.44	68.51	184.84	35.88	188.29	40.56	119.76	126.44	270.66	104.2	290.02	4.27	274.92
1	49.97	-53.39	73.13	182.68	41.35	187.30	35.09	115.08	120.31	267.74	103.04	286.89	3.93	271.67
1	54.58	-54.76	77.31	180.59	46.82	186.56	30.08	110.89	114.90	265.25	102.96	284.53	3.59	268.83
1	59.68	-56.23	82.00	178.43	52.28	185.93	25.30	106.27	109.24	263.41	102.32	282.58	3.36	266.77
1	64.62	-57.15	86.26	176.27	57.75	185.49	20.92	101.91	104.03	261.80	102.51	281.16	3.02	264.82
1	70.12	-58.17	91.11	174.20	63.21	185.31	16.77	97.10	98.54	261.10	102.14	280.36	2.68	263.77
1	75.42	-58.63	95.53	172.04	68.67	185.24	13.02	92.64	93.55	260.48	102.69	279.99	2.33	262.81
1	81.28	-59.15	100.52	169.87	74.15	185.35	9.51	87.67	88.18	260.67	102.67	280.16	1.99	262.66
1	87.37	-59.43	105.67	167.78	79.63	185.72	6.36	82.86	83.10	261.52	103.05	281.09	1.77	263.28
1	93.21	-59.20	110.42	165.62	85.09	186.20	3.56	78.26	78.34	262.38	104.15	282.30	1.42	263.81
1	99.64	-59.01	115.80	163.46	90.55	186.86	1.05	73.14	73.15	264.15	104.68	284.13	1.08	265.23
1	105.88	-58.34	120.89	161.37	96.02	187.77	-1.12	68.50	68.51	266.13	106.18	286.53	0.74	266.87
1	112.69	-57.67	126.59	159.21	101.49	188.80	-2.97	63.44	63.51	268.93	107.26	289.53	0.51	269.44
1	119.25	-56.54	131.97	157.05	106.96	190.01	-4.52	58.65	58.83	271.78	109.07	292.85	0.17	271.95
1	126.43	-55.40	138.04	154.89	112.42	191.39	-5.70	53.34	53.64	275.62	110.36	296.89	-0.17	275.45
1	131.11	-52.80	141.34	149.56	115.52	188.98	-6.51	47.48	47.93	274.16	110.2	295.48	-0.17	273.99
1	134.77	-49.57	143.60	142.51	117.25	184.54	-7.00	41.59	42.18	270.28	109.27	291.53	0.51	270.79
1	137.83	-45.93	145.28	135.85	119.03	180.62	-7.04	35.19	35.89	266.63	108.3	287.79	0.06	266.69
1	141.55	-42.31	147.74	128.97	120.44	176.46	-6.89	29.57	30.36	263.64	107.7	284.79	0.85	264.49
1	145.36	-38.48	150.37	122.43	121.83	172.72	-6.25	23.47	24.29	261.54	106.82	282.51	1.08	262.63

1	148.99	-34.42	152.91	115.88	122.98	168.97	-5.40	17.96	18.75	259.46	106.51	280.47	1.65	261.11
1	152.33	-30.10	155.27	109.80	124.36	165.89	-4.13	12.27	12.95	258.00	106.53	279.13	1.42	259.42
1	156.16	-25.69	158.26	103.61	125.16	162.48	-2.62	7.04	7.51	257.16	106.5	278.34	2.11	259.27
1	160.03	-21.08	161.41	97.62	126.06	159.44	-0.67	1.63	1.76	256.99	106.61	278.22	2.45	259.44
1	163.45	-16.22	164.25	91.88	126.97	156.73	1.43	-3.20	3.51	256.76	107.55	278.38	2.68	259.44
1	167.27	-11.21	167.65	86.26	127.63	154.04	4.05	-8.34	9.27	257.58	108.09	279.34	2.90	260.48
1	171.16	-6.02	171.26	80.64	127.94	151.24	6.86	-13.05	14.74	258.67	108.87	280.64	3.58	262.25
1	175.14	-0.62	175.14	75.27	128.36	148.80	10.24	-18.04	20.74	260.64	109.7	282.78	3.81	264.46
1	178.66	4.97	178.73	70.20	128.94	146.81	13.63	-22.34	26.17	262.49	111.57	285.21	3.93	266.42
1	182.60	10.75	182.91	65.11	128.97	144.47	17.69	-27.07	32.34	265.39	112.65	288.31	4.15	269.54
1	186.66	16.73	187.41	60.12	128.88	142.21	21.73	-31.10	37.94	268.50	114.51	291.90	4.95	273.46
1	190.19	22.85	191.56	55.56	129.17	140.62	26.16	-35.14	43.81	271.91	116.88	295.96	4.84	276.75
1	185.10	26.53	186.99	49.18	121.92	131.46	29.60	-37.93	48.11	263.88	110.53	286.09	5.18	269.06
1	179.45	30.13	181.97	43.16	114.76	122.61	33.03	-40.33	52.12	255.64	104.57	276.20	5.18	260.82
1	173.81	33.75	177.05	37.63	108.21	114.56	36.08	-41.88	55.27	247.51	100.08	266.98	5.29	252.81
1	168.23	37.36	172.33	32.32	101.62	106.64	39.57	-43.52	58.82	240.12	95.457	258.39	5.18	245.30
1	162.59	40.97	167.67	27.42	95.41	99.27	42.75	-44.47	61.69	232.76	91.907	250.24	5.18	237.93
1	156.97	44.59	163.18	22.75	88.96	91.82	46.24	-45.38	64.79	225.96	88.158	242.55	5.18	231.14
1	151.39	48.19	158.87	18.51	83.15	85.18	49.48	-45.61	67.30	219.38	85.724	235.53	5.18	224.55
1	145.75	51.80	154.68	14.52	77.18	78.53	52.91	-45.66	69.89	213.18	83.315	228.88	5.18	218.36
1	140.10	55.42	150.66	10.90	71.64	72.47	56.15	-45.17	72.07	207.15	81.899	222.75	5.18	212.33
1	134.46	59.03	146.84	7.56	65.90	66.33	59.71	-44.56	74.51	201.73	80.367	217.15	5.18	206.91
1	128.88	62.64	143.30	4.59	60.76	60.93	63.02	-43.35	76.49	196.49	80.049	212.17	5.18	201.67
1	123.23	66.24	139.91	1.92	55.37	55.40	66.51	-41.91	78.61	191.67	79.697	207.57	5.29	196.96
1	117.59	69.87	136.78	-0.41	50.63	50.63	69.82	-39.98	80.45	186.99	80.511	203.59	5.18	192.17
1	112.01	73.47	133.95	-2.41	45.64	45.70	73.48	-37.86	82.66	183.08	81.245	200.30	5.18	188.26
1	106.36	77.08	131.36	-4.10	41.12	41.32	76.81	-35.21	84.50	179.08	82.988	197.37	5.18	184.26
1	100.72	80.69	129.06	-5.42	36.44	36.84	77.60	-31.18	83.63	172.90	85.946	193.09	8.37	181.27
1	92.67	82.10	123.81	-6.40	31.95	32.59	81.50	-28.15	86.23	167.78	85.897	188.49	4.73	172.50
1	80.04	78.60	112.18	-6.75	26.52	27.37	76.48	-22.11	79.62	149.77	83.015	171.24	5.07	154.84
1	68.27	74.70	101.20	-6.78	21.61	22.65	71.77	-16.61	73.66	133.26	79.701	155.28	4.84	138.10
1	57.64	70.65	91.18	-6.45	17.11	18.28	67.22	-11.62	68.22	118.41	76.141	140.78	4.72	123.13

Table AII.2 continuation in rows instantaneous values of the measured data, CT model used to omit the errors

Irf(A)	Isf(A)	Itf(A)	Irf+Isf+Itf (A)	Pf	Qf	Sf	St=S+S0+Sf	3I0(A)
31.57	-12.48	-19.08	0.01	0.55	0.31	0.63	286.28	19
31.45	-12.16	-19.29	0	0.54	0.31	0.62	284.74	19
31.09	-11.19	-19.9	0	0.53	0.30	0.61	280.35	56
30.72	-10.22	-20.51	-0.01	0.53	0.30	0.61	276.48	56
30.36	-9.25	-21.12	-0.013	0.52	0.30	0.60	273.28	19
29.99	-8.28	-21.73	-0.022	0.52	0.29	0.59	270.38	19
29.63	-7.31	-22.35	-0.031	0.51	0.29	0.59	268.23	44
29.27	-6.34	-22.96	-0.033	0.51	0.29	0.59	266.77	56
28.90	-5.37	-23.57	-0.042	0.51	0.29	0.58	265.67	19
28.54	-4.40	-24.18	-0.041	0.51	0.29	0.58	265.30	56
28.18	-3.43	-24.79	-0.042	0.51	0.29	0.58	265.49	31
27.81	-2.46	-25.4	-0.051	0.51	0.29	0.59	266.38	-6
27.45	-1.49	-26.01	-0.053	0.51	0.29	0.59	267.78	-6
27.08	-0.52	-26.63	-0.072	0.51	0.29	0.59	269.41	31
26.72	0.45	-27.24	-0.074	0.52	0.30	0.60	272.11	31
26.36	1.42	-27.85	-0.073	0.52	0.30	0.61	275.32	-6
25.99	2.39	-28.46	-0.082	0.53	0.30	0.61	278.84	-6
25.63	3.36	-29.07	-0.083	0.54	0.31	0.62	283.01	31
24.99	4.29	-29.37	-0.092	0.54	0.31	0.62	282.03	-6
24.22	5.20	-29.51	-0.087	0.53	0.30	0.61	278.49	-69
23.45	6.12	-29.65	-0.085	0.52	0.30	0.60	275.29	-81
22.67	7.03	-29.79	-0.09	0.52	0.30	0.60	272.64	-144
21.90	7.94	-29.93	-0.087	0.51	0.29	0.59	270.63	-156
21.12	8.86	-30.07	-0.092	0.51	0.29	0.59	269.21	-231
20.35	9.77	-30.21	-0.09	0.51	0.29	0.58	268.10	-219
19.58	10.68	-30.35	-0.09	0.51	0.29	0.58	267.71	-294
18.81	11.60	-30.49	-0.08	0.50	0.29	0.58	267.69	-294
18.03	12.50	-30.63	-0.1	0.51	0.29	0.58	268.34	-331
17.26	13.42	-30.77	-0.09	0.51	0.29	0.59	269.50	-369
16.49	14.34	-30.91	-0.08	0.51	0.29	0.59	271.23	-394
15.71	15.25	-31.05	-0.09	0.51	0.30	0.59	273.46	-431
14.94	16.16	-31.19	-0.09	0.52	0.30	0.60	276.45	-469
14.17	17.08	-31.33	-0.08	0.53	0.30	0.61	279.75	-506
13.39	17.99	-31.47	-0.09	0.53	0.31	0.61	283.69	-531
12.62	18.90	-31.61	-0.09	0.54	0.31	0.62	288.04	-569

11.64	19.51	-31.25	-0.1	0.53	0.31	0.61	285.12	-619
10.67	20.12	-30.87	-0.08	0.52	0.30	0.61	281.82	-569
9.69	20.72	-30.51	-0.096	0.52	0.30	0.60	279.21	-569
8.72	21.33	-30.14	-0.093	0.51	0.30	0.59	277.11	-569
7.74	21.93	-29.77	-0.097	0.51	0.30	0.59	276.47	-606
6.77	22.54	-29.4	-0.093	0.50	0.29	0.58	275.48	-569
5.79	23.15	-29.03	-0.087	0.50	0.29	0.58	275.34	-594
4.82	23.75	-28.66	-0.094	0.50	0.29	0.58	275.26	-544
2.87	24.96	-27.92	-0.094	0.51	0.28	0.58	276.88	-544
1.89	25.57	-27.55	-0.088	0.51	0.28	0.58	278.49	-569
0.91	26.18	-27.18	-0.086	0.51	0.28	0.59	280.40	-544
-0.06	26.78	-26.82	-0.098	0.52	0.28	0.59	283.52	-556
-1.04	27.39	-26.45	-0.096	0.52	0.29	0.60	286.87	-569
-2.01	28.00	-26.08	-0.089	0.53	0.29	0.60	291.35	-581
-2.99	28.60	-25.71	-0.096	0.54	0.29	0.61	295.47	-544
-3.94	29.05	-25.2	-0.093	0.54	0.30	0.62	300.70	-581
-4.86	29.19	-24.43	-0.101	0.54	0.30	0.61	303.02	-531
-5.78	29.33	-23.65	-0.099	0.53	0.29	0.61	298.77	-506
-6.70	29.47	-22.88	-0.109	0.53	0.29	0.60	294.89	-469
-7.62	29.61	-22.1	-0.107	0.52	0.28	0.59	291.41	-431
-8.54	29.76	-21.32	-0.095	0.52	0.28	0.59	288.70	-394
-9.46	29.90	-20.55	-0.105	0.51	0.28	0.59	286.53	-369
-10.37	30.04	-19.77	-0.1	0.51	0.28	0.58	284.75	-331
-11.29	30.17	-19	-0.12	0.51	0.28	0.58	283.62	-294
-12.21	30.31	-18.22	-0.12	0.51	0.28	0.58	282.90	-256
-13.13	30.45	-17.45	-0.13	0.51	0.28	0.58	282.73	-219
-14.05	30.59	-16.67	-0.13	0.52	0.28	0.59	283.44	-194
-14.97	30.73	-15.89	-0.13	0.52	0.28	0.59	284.31	-156
-15.89	30.87	-15.12	-0.14	0.52	0.28	0.59	285.81	-119
-16.81	31.02	-14.34	-0.13	0.53	0.28	0.60	287.87	-81
-17.72	31.16	-13.56	-0.12	0.54	0.29	0.61	290.65	-57
-18.64	31.30	-12.79	-0.13	0.54	0.29	0.62	293.63	-19
-19.36	31.11	-11.88	-0.13	0.55	0.29	0.62	297.34	19
-19.97	30.74	-10.9	-0.13	0.54	0.29	0.61	295.92	19
-20.59	30.38	-9.921	-0.131	0.53	0.29	0.61	292.65	-56
-21.20	30.02	-8.945	-0.125	0.53	0.28	0.60	288.44	-6
-21.82	29.66	-7.965	-0.125	0.52	0.28	0.59	286.24	-94
-22.43	29.30	-6.988	-0.118	0.52	0.28	0.59	284.19	-119

-23.04	28.94	-6.009	-0.109	0.52	0.28	0.59	282.71	-181
-23.66	28.58	-5.032	-0.112	0.52	0.27	0.58	281.14	-156
-24.27	28.22	-4.053	-0.103	0.51	0.27	0.58	281.03	-231
-24.89	27.86	-3.076	-0.106	0.52	0.27	0.58	281.25	-269
-25.50	27.49	-2.097	-0.107	0.52	0.27	0.58	281.64	-294
-26.12	27.13	-1.12	-0.11	0.52	0.28	0.59	282.83	-319
-26.73	26.77	-0.14	-0.1	0.52	0.28	0.59	284.82	-394
-27.34	26.41	0.836	-0.094	0.53	0.28	0.60	287.20	-419
-27.96	26.05	1.816	-0.094	0.53	0.28	0.60	289.75	-432
-28.57	25.69	2.793	-0.087	0.54	0.29	0.61	293.07	-456
-29.19	25.33	3.769	-0.091	0.55	0.29	0.62	297.47	-544
-29.30	24.58	4.634	-0.086	0.55	0.29	0.62	301.42	-531
-29.42	23.84	5.495	-0.085	0.53	0.28	0.60	291.87	-569
-29.53	23.09	6.357	-0.083	0.51	0.27	0.58	281.96	-569
-29.65	22.34	7.218	-0.092	0.50	0.26	0.56	272.84	-581
-29.77	21.60	8.08	-0.09	0.48	0.25	0.54	264.12	-569
-29.88	20.85	8.945	-0.085	0.47	0.24	0.53	255.95	-569
-30.00	20.10	9.806	-0.094	0.46	0.23	0.51	248.24	-569
-30.11	19.36	10.67	-0.08	0.44	0.23	0.50	241.21	-569
-30.23	18.61	11.53	-0.09	0.43	0.22	0.48	234.55	-569
-30.34	17.86	12.39	-0.09	0.42	0.22	0.47	228.40	-569
-30.46	17.12	13.26	-0.08	0.41	0.21	0.46	222.79	-569
-30.58	16.37	14.12	-0.09	0.40	0.21	0.45	217.80	-569
-30.69	15.63	14.98	-0.08	0.39	0.21	0.44	213.31	-581
-30.81	14.88	15.84	-0.09	0.38	0.21	0.43	209.20	-569
-30.93	14.13	16.7	-0.1	0.37	0.21	0.42	205.90	-569
-31.04	13.39	17.57	-0.08	0.36	0.22	0.42	202.97	-569
-30.98	12.58	18.3	-0.1	0.35	0.22	0.41	201.86	-919
-30.55	11.68	18.79	-0.08	0.33	0.22	0.40	193.61	-519
-30.13	10.76	19.27	-0.1	0.32	0.22	0.38	176.69	-557
-29.70	9.85	19.76	-0.095	0.30	0.22	0.37	160.49	-532
-29.28	8.94	20.24	-0.098	0.29	0.22	0.36	145.86	-519

Table AII.3. Instantaneous values of the recorded currents data. Assumed A/D records error omitted from the summation of the currents.

Table AII.3 Instantaneous values of the recorded currents data. Assumed A/D records error omitted from the summation of the currents:

CURSOR	TIME	Ir	Is	It	3I0=Ir+Is+It	Assumed A/D Error	3I0-A/D Error
-984	-98.4	1.123	-0.314	-0.808	0.001	0	0.001
-983	-98.3	1.117	-0.303	-0.813	0.001	0	0.001
-982	-98.2	1.1	-0.266	-0.83	0.004	0	0.004
-981	-98.1	1.081	-0.227	-0.85	0.004	0	0.004
-980	-98	1.061	-0.19	-0.87	0.001	0	0.001
-979	-97.9	1.041	-0.151	-0.889	0.001	0	0.001
-978	-97.8	1.024	-0.115	-0.906	0.003	0	0.003
-977	-97.7	1.005	-0.075	-0.926	0.004	0	0.004
-976	-97.6	0.985	-0.039	-0.945	0.001	0	0.001
-975	-97.5	0.968	-0.002	-0.962	0.004	0	0.004
-974	-97.4	0.948	0.036	-0.982	0.002	0	0.002
-973	-97.3	0.929	0.072	-1.002	-0.001	0	-0.001
-972	-97.2	0.909	0.112	-1.022	-0.001	0	-0.001
-971	-97.1	0.892	0.148	-1.038	0.002	0	0.002
-970	-97	0.872	0.188	-1.058	0.002	0	0.002
-969	-96.9	0.853	0.224	-1.078	-0.001	0	-0.001
-968	-96.8	0.833	0.263	-1.097	-0.001	0	-0.001
-967	-96.7	0.816	0.3	-1.114	0.002	0	0.002
-966	-96.6	0.788	0.334	-1.123	-0.001	0	-0.001
-965	-96.5	0.755	0.362	-1.123	-0.006	0	-0.006
-964	-96.4	0.724	0.392	-1.123	-0.007	-0.00274125	-0.00425875
-963	-96.3	0.69	0.421	-1.123	-0.012	-0.007881094	-0.004118906
-962	-96.2	0.659	0.451	-1.123	-0.013	-0.014627139	0.001627139
-961	-96.1	0.625	0.479	-1.123	-0.019	-0.021935354	0.002935354
-960	-96	0.595	0.51	-1.123	-0.018	-0.028786806	0.010786806
-959	-95.9	0.561	0.538	-1.123	-0.024	-0.034439254	0.010439254
-958	-95.8	0.53	0.569	-1.123	-0.024	-0.03856083	0.01456083
-957	-95.7	0.496	0.6	-1.123	-0.027	-0.041210415	0.014210415
-956	-95.6	0.465	0.628	-1.123	-0.03	-0.042700807	0.012700807
-955	-95.5	0.432	0.659	-1.123	-0.032	-0.043425302	0.011425302
-954	-95.4	0.401	0.687	-1.123	-0.035	-0.043724157	0.008724157

-953	-95.3	0.367	0.718	-1.123	-0.038	-0.043826039	0.005826039
-952	-95.2	0.336	0.746	-1.123	-0.041	-0.043853632	0.002853632
-951	-95.1	0.303	0.777	-1.123	-0.043	-0.043859204	0.000859204
-950	-95	0.272	0.805	-1.123	-0.046	-0.04385995	-0.00214005
-949	-94.9	0.232	0.827	-1.109	-0.05	-0.04386	-0.00614
-948	-94.8	0.196	0.85	-1.092	-0.046	-0.04386	-0.00214
-947	-94.7	0.157	0.872	-1.075	-0.046	-0.04386	-0.00214
-946	-94.6	0.12	0.892	-1.058	-0.046	-0.04386	-0.00214
-945	-94.5	0.081	0.914	-1.044	-0.049	-0.04386	-0.00514
-944	-94.4	0.044	0.937	-1.027	-0.046	-0.04386	-0.00214
-943	-94.3	0.005	0.957	-1.01	-0.048	-0.04386	-0.00414
-942	-94.2	-0.03	0.979	-0.993	-0.044	-0.04386	-0.00014
-941	-94.1	-0.067	1.002	-0.979	-0.044	-0.04386	-0.00014
-940	-94	-0.106	1.022	-0.962	-0.046	-0.04386	-0.00214
-939	-93.9	-0.143	1.044	-0.945	-0.044	-0.04386	-0.00014
-938	-93.8	-0.182	1.066	-0.929	-0.045	-0.04386	-0.00114
-937	-93.7	-0.218	1.086	-0.914	-0.046	-0.04386	-0.00214
-936	-93.6	-0.258	1.109	-0.898	-0.047	-0.04386	-0.00314
-935	-93.5	-0.294	1.131	-0.881	-0.044	-0.04386	-0.00014
-934	-93.4	-0.334	1.151	-0.864	-0.047	-0.04386	-0.00314
-933	-93.3	-0.367	1.168	-0.844	-0.043	-0.04386	0.00086
-932	-93.2	-0.398	1.168	-0.811	-0.041	-0.04111875	0.00011875
-931	-93.1	-0.426	1.168	-0.78	-0.038	-0.035978906	-0.002021094
-930	-93	-0.457	1.168	-0.746	-0.035	-0.029232861	-0.005767139
-929	-92.9	-0.485	1.168	-0.715	-0.032	-0.021924646	-0.010075354
-928	-92.8	-0.516	1.168	-0.682	-0.03	-0.015073194	-0.014926806
-927	-92.7	-0.544	1.168	-0.651	-0.027	-0.009420746	-0.017579254
-926	-92.6	-0.575	1.168	-0.617	-0.024	-0.00529917	-0.01870083
-925	-92.5	-0.603	1.168	-0.586	-0.021	-0.002649585	-0.018350415
-924	-92.4	-0.634	1.168	-0.552	-0.018	-0.001159193	-0.016840807
-923	-92.3	-0.665	1.168	-0.519	-0.016	-0.000434698	-0.015565302
-922	-92.2	-0.693	1.168	-0.488	-0.013	-0.000135843	-0.012864157
-921	-92.1	-0.724	1.168	-0.454	-0.01	-3.39607E-05	-0.009966039
-920	-92	-0.752	1.168	-0.423	-0.007	-6.36764E-06	-0.006993632
-919	-91.9	-0.783	1.168	-0.39	-0.005	-7.95955E-07	-0.004999204
-918	-91.8	-0.811	1.168	-0.359	-0.002	-4.97472E-08	-0.00199995
-917	-91.7	-0.842	1.168	-0.325	0.001	-1.78671E-22	0.001

-916	-91.6	-0.864	1.156	-0.291	0.001	-0.00274125	0.00374125			
-915	-91.5	-0.884	1.137	-0.258	-0.005	-0.007881094	0.002881094			
-914	-91.4	-0.9	1.12	-0.221	-0.001	-0.014627139	0.013627139			
-913	-91.3	-0.92	1.1	-0.188	-0.008	-0.021935354	0.013935354			
-912	-91.2	-0.94	1.081	-0.151	-0.01	-0.028786806	0.018786806			
-911	-91.1	-0.959	1.061	-0.117	-0.015	-0.034439254	0.019439254			
-910	-91	-0.976	1.044	-0.081	-0.013	-0.03856083	0.02556083			
-909	-90.9	-0.996	1.024	-0.047	-0.019	-0.041210415	0.022210415			
-908	-90.8	-1.016	1.005	-0.011	-0.022	-0.042700807	0.020700807			
-907	-90.7	-1.033	0.987	0.022	-0.024	-0.043425302	0.019425302			
-906	-90.6	-1.052	0.968	0.058	-0.026	-0.043724157	0.017724157			
-905	-90.5	-1.072	0.948	0.092	-0.032	-0.043826039	0.011826039			
-904	-90.4	-1.092	0.929	0.129	-0.034	-0.043853632	0.009853632			
-903	-90.3	-1.109	0.912	0.162	-0.035	-0.043859204	0.008859204			
-902	-90.2	-1.128	0.892	0.199	-0.037	-0.04385995	0.00685995			
-901	-90.1	-1.148	0.872	0.232	-0.044	-0.04386	-0.00014			
-900	-90	-1.165	0.856	0.266	-0.043	-0.04386	0.00086			
-899	-89.9	-1.168	0.822	0.3	-0.046	-0.04386	-0.00214			
-898	-89.8	-1.168	0.788	0.334	-0.046	-0.04386	-0.00214			
-897	-89.7	-1.168	0.757	0.364	-0.047	-0.04386	-0.00314			
-896	-89.6	-1.168	0.724	0.398	-0.046	-0.04386	-0.00214			
-895	-89.5	-1.168	0.693	0.429	-0.046	-0.04386	-0.00214			
-894	-89.4	-1.168	0.659	0.463	-0.046	-0.04386	-0.00214			
-893	-89.3	-1.168	0.628	0.494	-0.046	-0.04386	-0.00214			
-892	-89.2	-1.168	0.595	0.527	-0.046	-0.04386	-0.00214			
-891	-89.1	-1.168	0.564	0.558	-0.046	-0.04386	-0.00214			
-890	-89	-1.168	0.53	0.592	-0.046	-0.04386	-0.00214			
-889	-88.9	-1.168	0.499	0.623	-0.046	-0.04386	-0.00214			
-888	-88.8	-1.168	0.465	0.656	-0.047	-0.04386	-0.00314			
-887	-88.7	-1.168	0.435	0.687	-0.046	-0.04386	-0.00214			
-886	-88.6	-1.168	0.401	0.721	-0.046	-0.04386	-0.00214			
-885	-88.5	-1.168	0.37	0.752	-0.046	-0.04386	-0.00214			

APPENDIX III

SYSTEM FAULT AND LOAD FLOW STUDIES

III.1 INITIAL CONDITION AND LOAD FLOW STUDIES

The initial condition prior to the fault plays an important rule during the studies. To find out the initial condition prior to the fault the following records are investigated:

a) Records of the fault currents and voltages from REG216 (figure 2). From this record it can be recognized that the voltage and current angle differences prior to the fault are as the followings:

In point -98: The instantaneous values of the currents: IR=1.123In, IS=-0.314In, IT=-0.808In considering +/-120 degree phase angles, the current waves would be: IR=1.168InSIN(wt+104.4) IS=1.168InSIN(wt+104.4-120) IT=1.168InSIN(wt+104.4+120). 1.168In is the maximum value of the current, can be obtained from the record for unfaulted phase i.e. phase S. The errors exists between the instantaneous values of the currents and the formula obtained, are either because of the CT errors, considered in appendix II, or unbalanced operation.

The phase angles between the current and the voltage waveforms are very trustable. Therefore, they are used to obtain the MVAR generation of unit number seven prior to the fault. The phase angle between the voltage and currents are obtained as the followings:

Peak of phase S current: 1.168In
The instantaneous current of phase S in peak of Vst=0.805In
Phase difference=Arcsin(0.805/1.168)-90=43.6-90 = -46.4 Degree
Phase difference between Vs and Vst= -30 Degree
Phase difference between Vs and Is = - 16.4 Degree

Assuming that the active power output was 280MW, we obtain the MVAR output as 82.4 MVAR

b) From measuring equipment, the voltage of the 400KV busbar was measured and written to be 420 KV for unit 8. However, this measuring must be corrected according to the test obtained recently from unit 8 measuring device by the following correction:

405*413/420=398.25KV = 0.996 P.U. in 400KV base. The incoming voltage would be 0.997 P.U.

The magnitude of voltage of unit 7 can be obtained from the records to be: 156.7/(1.41)=111.13 divide this by recording relationship that is 1.1, we obtain Vg=1.01 P.U.

The magnitude of current is I=SQRT(280*280+82.4*82.4)/(1.731*1.01*15.75) = 10.599KA

This is in close agreement with the value can be obtained from the record i.e. 1.168*12500/1.4=10.428KA

Putting all these together in a load flow calculation environment the load flow condition prior to the fault can be obtained. This is P=280MW and Q=82.15MVAR Vg=1,01 P.U. and Vnet=0.997 P.U.

On the other hand, from the table AII.2 created in appendix II, the power MW and MVARs can be read in each instant of time, prior to single and double phase faults.

These are:

P=263MW and Q=100.4 MVAR prior to single phase fault
P=277MW and Q=116.7 MVAR prior to double phase fault

Remembering from appendix I that Q values are just valid for balanced and without harmonic circuits. However, the approximation is valid for our purposes.

Double phase fault is the major fault needs to be studied in the next section therefore; the following load flow conditions are recognized:

P=277MW , Q=116.7MVAR , Vg=1.01P.U. , Vnet=0.979 P.U.

Considering the above discussions, and that the Q values obtained in the fault condition are not reliable values, and that the objective of this section which is fault level studies are not too much tolerated by the adjustments of these variables under the above boundary values, the following load flow conditions are assumed:

P=280MW
Q=82MVA
Vg=1.01P.U.
Vnet=0.997P.U.

The service station consumptions are also ignored. The results of load flow studies are shown in figures AIII.1 and AIII.2.

Figure AIII.1: Load flow study of the plant, P.U. voltage magnitudes and angles, MW-MVAR flows are shown

LOAD FLOW RESULTS - BUSBAR PU VOLTS / ANGLE & LINE MW(KW) / MVAR(KVAR) LOADING

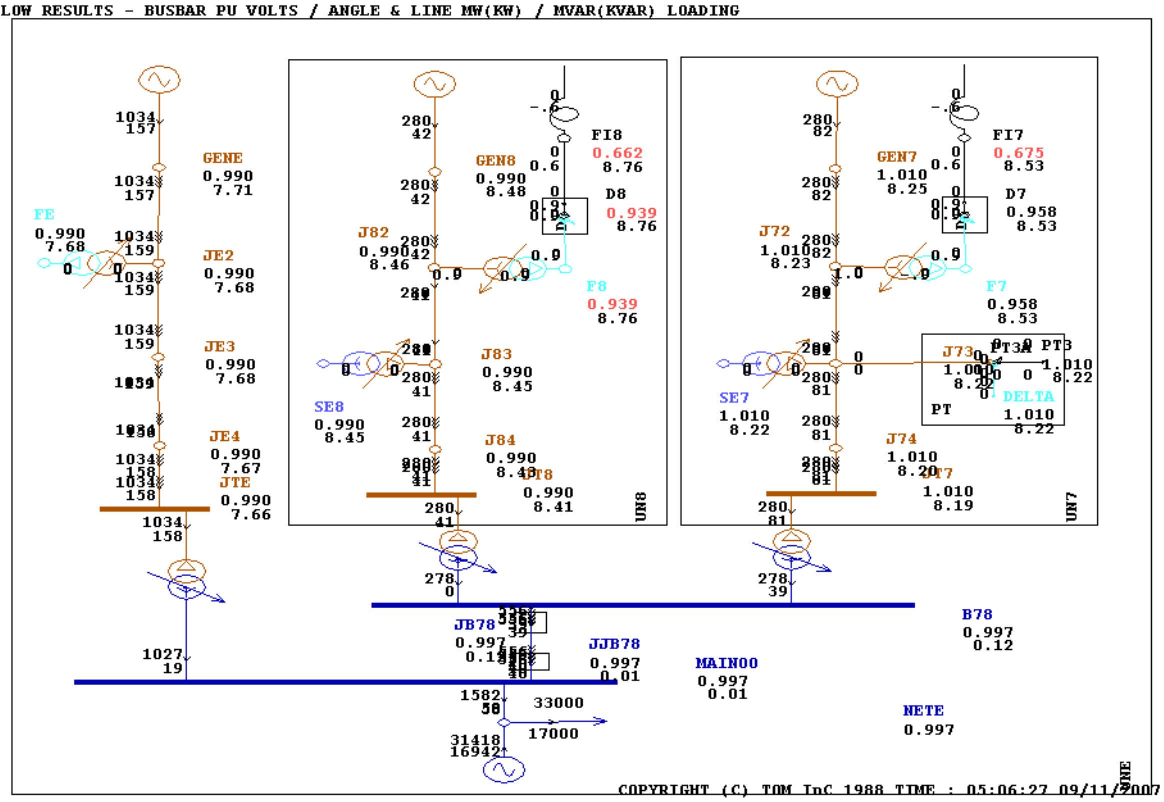


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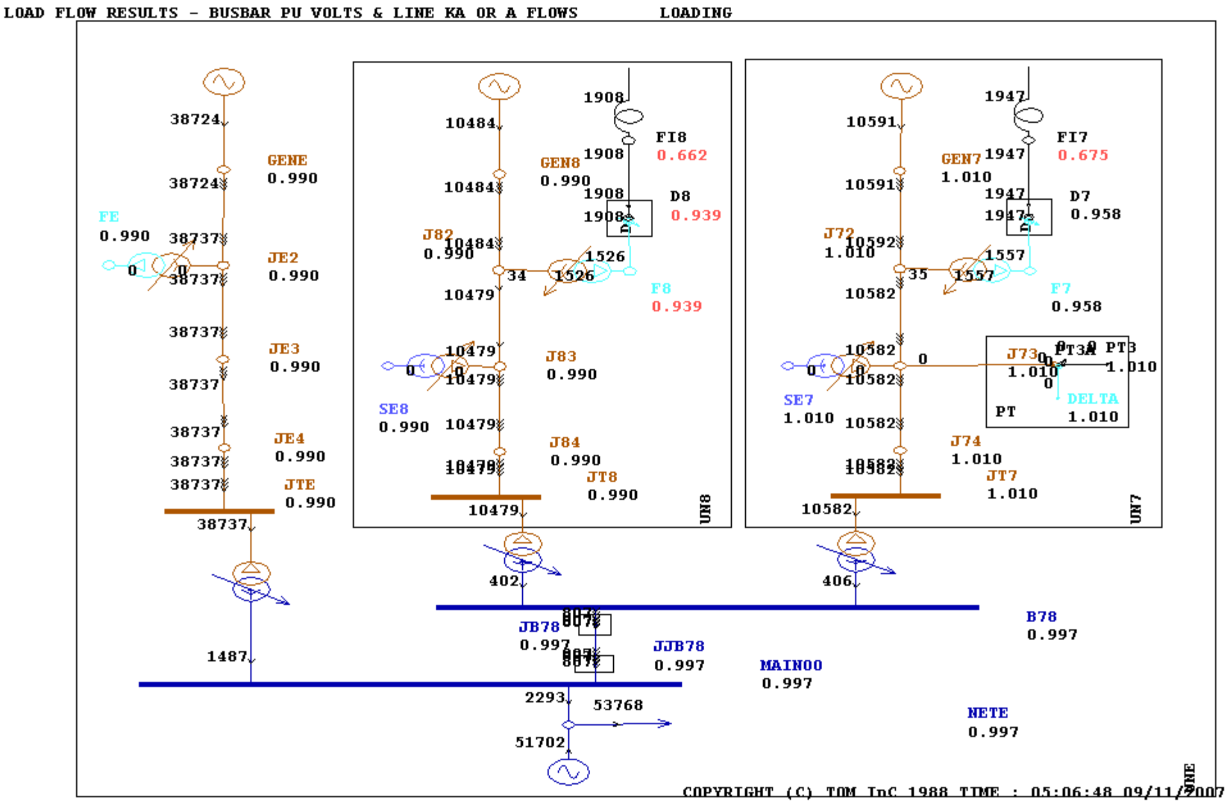
Figure AIII.2: Load flow study of the plant, P.U. voltage magnitudes and angles, current flows in Amper are shown



III.2 FAULT STUDIES:

Figures and listings provided in this section show the fault studies results. Since the generator has an internal four parallel windings, and the intermediate fault is just occurred in one of these windings, four generators are used to equalize the model of unit number 7 in the following fault studies. In this way, the generator located in junction GEN7 is the one that we put the internal faults. The currents contributions from the network would be those passing through the line between junctions J73 and J72 and the actual currents passing to the neutral would be the sum of the neutral intermediate winding fault current and those coming from the other three windings, these are the current passing through 3GEN7 toward GEN7.

Refer to the figures and listings provided in this section the fault studies calculation results are reported in two categories. The first one lists the fault results and the second one shows these results on single line diagram.

The following drawings and lists are reported:

(1) Figure AIII.3 shows line to line fault levels (reported as maximum currents) for all the busbars of the system.

(2) Figure AIII.4 shows the result of LL fault occurring in the slots 326 and 327 between phase R and T. Please read phase Yellow as phase T and phase Blue as phase R and phase Red as phase S. There are no much difference between this result and the LLG faults occurring in the slots 326, 327, and 217 (single phase fault) when the ferroresonace situations described in appendix VII are not considered.

(3) The above fault flow result listings are provided in table AIII.1. Please read phase Yellow as phase T and phase Blue as phase R and phase Red as phase S.

(4) Figure AIII.5, shows the same result as the previous for LLG fault study by impedance of 0.012 P.U. Unfortunately, the PASHA program is not capable of considering the fault impedance between the two phases and to ground simultaneously and neither can put the ground portion of the fault in another location as it happened in the actual system, in the present time.

(5) Table AIII.2, shows the previous fault analysis list, with the readings mentioned in item 3 above.

(6) Table AIII.3, shows the result of line to line fault when R phase in slot 127 is connected to T phase in slot 126 (phase R to the neutral point). According to the section 5 this fault is not the initial two phase fault.

(7) Figure AIII.6 shows the flowing of 3I0 for LG faults with introducing the ferroresonance effect, due to the lose earth connection in the secondary side. The fault is located in J72 for flows clarity.

In all result lists the P.U. bases are as the followings:

P.U. base is 15.75KV for line to line voltages and (100*1000 / 15.75*1.73205=3666A) Amper for currents in 15.75KV sections and 400KV for voltages and (100*1000 / 400*1.73205=1443.4A) Amper for 400KV sections.

Figure AIII.3: shows line to line fault levels (reported as maximum currents) for all the busbars of the system.

LINE TO LINE FAULT LEVEL (MVA) FOR EACH BUSBAR AT T= 0.0mS

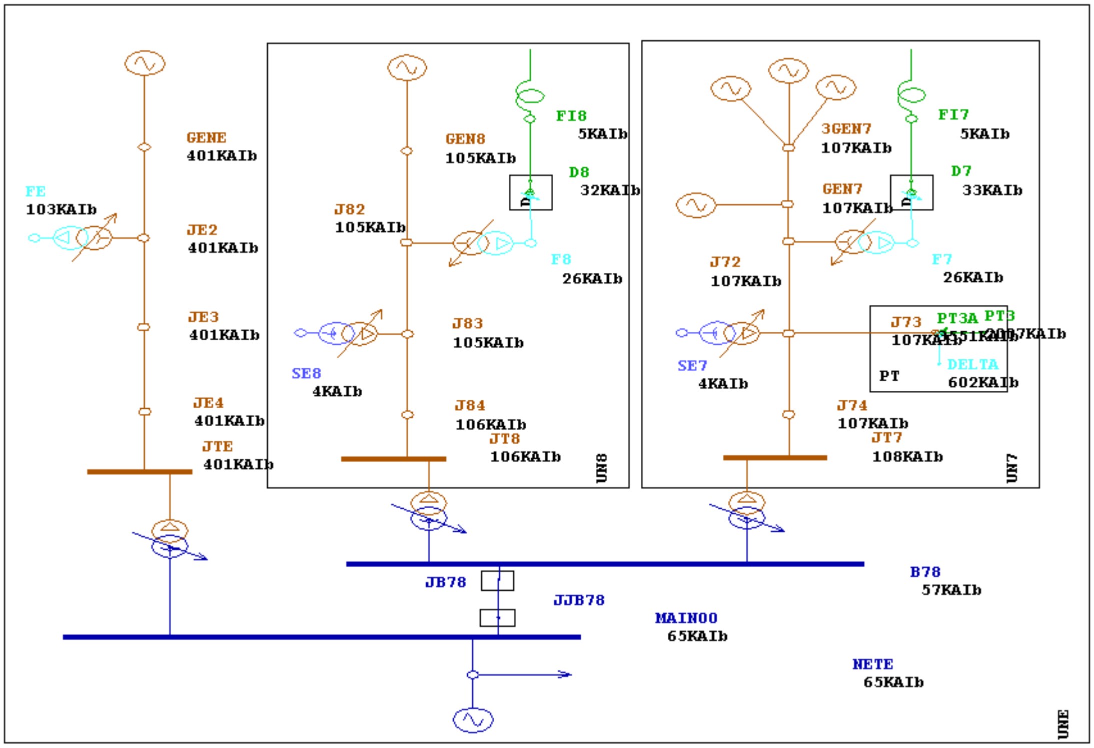


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Figure AIII.4: shows the result of LL fault occurring in the slots 326 and 327 between phase R and T. Please read phase Yellow as phase T and phase Blue as phase R and phase Red as phase S. There are no much difference between this result and the LLG faults occurring in the slots 326, 327, and 217 (single phase fault) when the ferroresonace situations described in appendix VII are not considered.

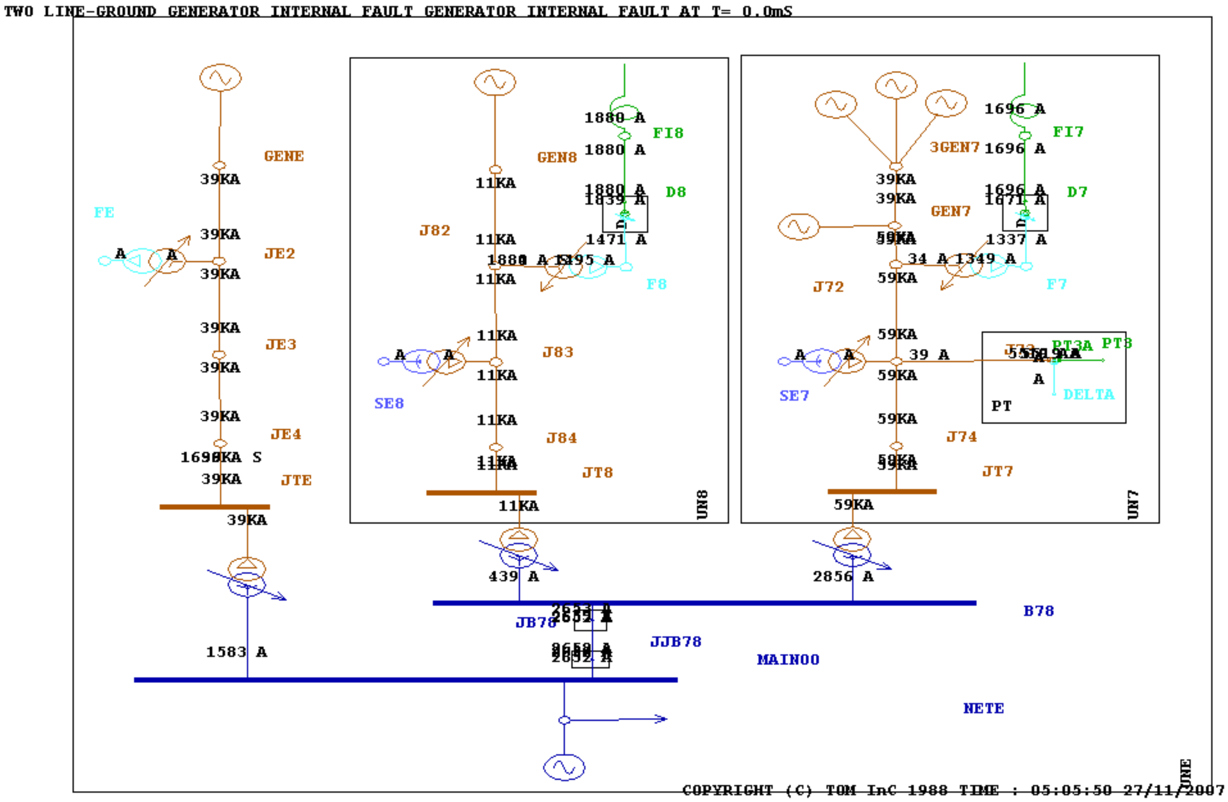


Table AIII.1 the fault flow result listings of figure III.4. Please read phase Yellow as phase T and phase Blue as phase R and phase Red as phase S.

```
UNBALANCED FAULT STUDY RESULTS
 ==============================

 SYSTEM TITLE : X 3GENERATOR
 STUDY  TITLE :
 FAULT IMPEDANCE (R AND X) =    0.0000   0.0000 PU

 TIME AFTER FAULT INCIDENCE =      0.00 MSEC

 LINE TO LINE

-INTERNAL FAULT IN GENERATOR
 ---------------------------
  WINDING PERCENT FROM TERMINAL

  PHASE B:  88.      PHASE C:  75.

                         RED PHASE      YELLOW PHASE      BLUE PHASE

                      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)
  NEUTRAL SIDE         1.6599    8.82   8.6769    8.22  10.3367 -171.68
  TERMINAL SIDE        1.6599    8.82  26.8864 -171.25  25.2265    8.75

-B U S B A R   AC   V O L T A G E S
 -----------------------------------

 BUSBAR          RED  PHASE        YELLOW  PHASE          BLUE  PHASE                  PHASE TO PHASE       AREA
             MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)      MAG(PU)    MAG(PU)    MAG(PU)

 3GEN7         1.013    29.850      0.526  -149.270      0.487  -151.100         0.889      0.024      0.866   UN7
 J72           1.013    29.843      0.526  -149.305      0.487  -151.079         0.889      0.025      0.866   UN7
 J73           1.013    29.842      0.526  -149.124      0.487  -151.276         0.888      0.025      0.866   UN7
 J74           1.013    29.841      0.526  -148.942      0.487  -151.474         0.888      0.026      0.866   UN7
 JT7           1.013    29.840      0.526  -148.760      0.487  -151.671         0.888      0.027      0.866   UN7

 PT3           0.888    30.195      0.025  -124.260      0.866  -150.521         0.526      0.487      1.013   PT
 PT3A          1.013    29.842      0.526  -149.124      0.487  -151.276         0.888      0.025      0.866   PT
 DELTA         0.888    30.195      0.025  -124.260      0.866  -150.521         0.526      0.487      1.013   PT

 JB78          0.999     0.808      0.978  -121.051      0.961   120.977         0.998      0.959      0.981
 JJB78         1.000     0.621      0.979  -120.920      0.967   120.955         0.997      0.963      0.985
 GEN7          1.013    29.843      0.526  -149.351      0.487  -151.029         0.889      0.024      0.866   UN7


 B R A N C H     C U R R E N T S
 ------------------------------- THE DIRECTION OF CURRENTS ARE FROM SENDING TO RECEIVINGS

       BUSBAR             RED PHASE      YELLOW PHASE      BLUE PHASE     AREA-TO-AREA

   FROM       TO      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)

 J72       J73          0.8634  -49.99  16.7844   36.90  16.8533 -146.03   UN7    UN7
 J73       J72          0.8634  -49.99  16.7844   36.90  16.8533 -146.03
 J73       J74          0.8637  -49.99  16.7846   36.90  16.8536 -146.03   UN7    UN7
 J74       J73          0.8637  -49.99  16.7846   36.90  16.8536 -146.03
 J74       JT7          0.8637  -49.99  16.7846   36.90  16.8536 -146.03   UN7    UN7
 JT7       J74          0.8637  -49.99  16.7846   36.90  16.8536 -146.03

 NETE      MAIN00      18.6946 -170.57   2.2243   87.63  18.3693    2.62   UNE    UNE
 MAIN00    NETE        18.6946 -170.57   2.2243   87.63  18.3693    2.62
```

```
MAIN00    JTE          8.8550 -161.76   9.1661   75.68   8.6640  -44.84  UNE    UNE
JTE       MAIN00       8.8909 -132.50   8.7104  104.50   8.3994  -12.92

B78       JT8          1.6663 -155.11   1.8828   76.54   1.5584  -46.47  UNE    UN8
JT8       B78          1.7979 -127.60   1.7036  102.11   1.4740   -9.42
J83       SE8          0.0000   30.00   0.0000   30.00   0.0000   30.00  UN8    UN8
SE8       J83          0.0000   30.00   0.0000   30.00   0.0000   30.00
PT3       PT3A         0.0000   30.00   0.0000   30.00   0.0000   30.00  PT     PT
PT3A      PT3          0.0000   30.00   0.0000   30.00   0.0000   30.00

PT3A      J73          0.0000   30.00   0.0000   30.00   0.0000   30.00  PT     UN7
J73       PT3A         0.0000   30.00   0.0000   30.00   0.0000   30.00
PT3A      DELTA        0.0000   30.00   0.0000   30.00   0.0000   30.00  PT     PT
DELTA     PT3A         0.0000   30.00   0.0000   30.00   0.0000   30.00
JB78      B78         10.7735 -154.93   7.5272 -141.36  18.1766   30.64         UNE
B78       JB78        10.7735 -154.93   7.5272 -141.36  18.1766   30.64

MAIN00    JJB78       10.7682 -155.00   7.5225 -141.27  18.1637   30.64  UNE
JJB78     MAIN00      10.7682 -155.00   7.5225 -141.27  18.1637   30.64
JJB78     JB78        10.7707 -154.97   7.5249 -141.31  18.1700   30.64
JB78      JJB78       10.7707 -154.97   7.5249 -141.31  18.1700   30.64
3GEN7     GEN7         1.8906   11.28  10.1234 -138.21   8.5487   48.24  UN7    UN7
GEN7      3GEN7        1.8906   11.28  10.1234 -138.21   8.5487   48.24

GEN7      J72          0.8761  -50.12  16.7843   36.93  16.8522 -146.05  UN7    UN7
J72       GEN7         0.8761  -50.12  16.7843   36.93  16.8522 -146.05


SUBSTATION/S FEEDINGS CURRENTS
-------------------------------

      BUSBAR             RED PHASE      YELLOW PHASE      BLUE PHASE

  FROM       TO      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)

3GEN7     GEN7         1.8906   11.28  10.1234 -138.21   8.5487   48.24
GEN7      3GEN7        1.8906   11.28  10.1234 -138.21   8.5487   48.24
GEN7      J72          0.8761  -50.12  16.7843   36.93  16.8522 -146.05
J72       GEN7         0.8761  -50.12  16.7843   36.93  16.8522 -146.05
```

Figure AIII.5, shows the same result as the previous for LLG fault study by impedance of 0.012 P.U. Unfortunately, the PASHA program is not capable of considering the fault impedance between the two phases and to ground simultaneously and neither can put the ground portion of the fault in another location as it happened in the actual system, in the present time.

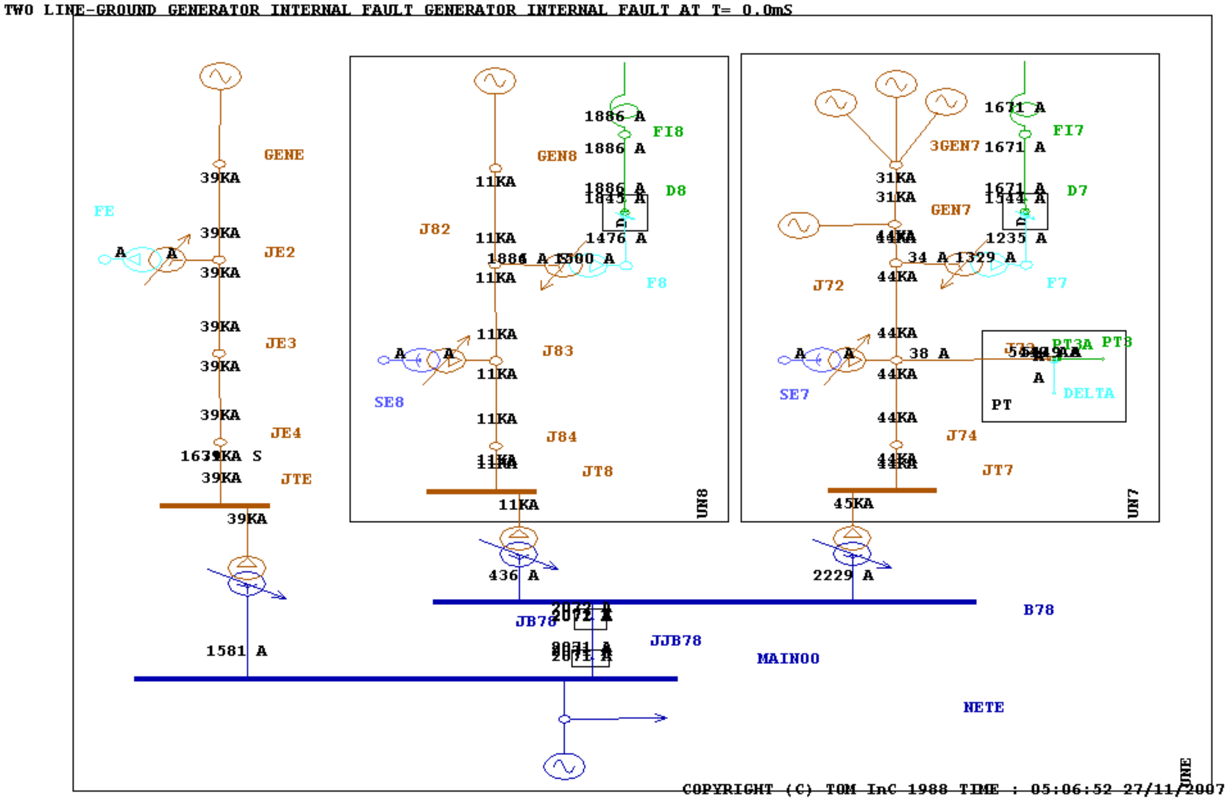


Table AIII.2, shows the same result as the previous for LLG fault study by impedance of 0.012 P.U. Unfortunately, the PASHA program is not capable of considering the fault impedance between the two phases and to ground simultaneously and neither can put the ground portion of the fault in another location as it happened in the actual system, at its present version.

```
UNBALANCED FAULT STUDY RESULTS
 ==============================

 SYSTEM TITLE : X 3GENERATOR
 STUDY  TITLE :
 FAULT IMPEDANCE (R AND X) =    0.0000    0.0120 PU

 TIME AFTER FAULT INCIDENCE =      0.00 MSEC

 LINE TO LINE TO GROUND

-INTERNAL FAULT IN GENERATOR
 ----------------------------
  WINDING PERCENT FROM TERMINAL

  PHASE B:  88.      PHASE C:  75.

                         RED PHASE      YELLOW PHASE      BLUE PHASE

                      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)
  NEUTRAL SIDE         1.0663   10.34   6.7126    9.58  7.7785 -170.32
  TERMINAL SIDE        1.0663   10.34  20.3729 -169.93  19.3075   10.14

-B U S B A R   AC   V O L T A G E S
 ----------------------------------

 BUSBAR          RED  PHASE        YELLOW  PHASE          BLUE  PHASE                  PHASE TO PHASE       AREA
             MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)      MAG(PU)    MAG(PU)    MAG(PU)

 3GEN7         1.416    34.884      0.202   -76.569      0.244   148.302         0.867      0.238      0.883   UN7
 J72           1.416    34.874      0.201   -76.649      0.243   148.259         0.867      0.237      0.883   UN7
 J73           1.416    34.868      0.202   -76.534      0.245   148.112         0.867      0.239      0.883   UN7
 J74           1.416    34.862      0.204   -76.420      0.246   147.965         0.867      0.240      0.883   UN7
 JT7           1.416    34.856      0.205   -76.308      0.247   147.820         0.867      0.242      0.883   UN7

 NETE          0.997     0.739      0.981  -120.431      0.972   120.960         0.995      0.970      0.986   UNE
 GENE          0.987    37.303      0.966   -82.365      0.981   158.523         0.975      0.969      0.990   UNE
 JE2           0.987    37.277      0.966   -82.392      0.981   158.497         0.975      0.969      0.990   UNE
 JE3           0.987    37.268      0.966   -82.401      0.981   158.489         0.975      0.969      0.990   UNE
 JE4           0.987    37.260      0.966   -82.410      0.981   158.480         0.975      0.969      0.990   UNE

 MAIN00        0.997     0.751      0.981  -120.426      0.972   120.968         0.995      0.970      0.985   UNE
 PT3           0.867    42.081      0.239   -51.996      0.883  -153.585         0.529      0.554      1.001   PT
 PT3A          1.001    34.177      0.529  -122.828      0.554  -167.703         0.867      0.239      0.883   PT
 DELTA         0.867    42.081      0.239   -51.996      0.883  -153.585         0.529      0.554      1.001   PT

 JB78          0.996     0.957      0.981  -120.474      0.967   121.035         0.995      0.966      0.982
 JJB78         0.997     0.762      0.981  -120.429      0.971   120.971         0.995      0.969      0.985
 GEN7          1.416    34.876      0.201   -76.678      0.243   148.297         0.867      0.237      0.883   UN7


 B R A N C H     C U R R E N T S
 ------------------------------- THE DIRECTION OF CURRENTS ARE FROM SENDING TO RECEIVINGS

       BUSBAR                  RED PHASE      YELLOW PHASE      BLUE PHASE     AREA-TO-AREA

   FROM       TO      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)

 J72       J73          1.6448    11.58  12.0452    33.00  13.5865 -149.40   UN7    UN7
```

```
J73       J72          1.6448   11.58  12.0452   33.00  13.5865 -149.40
J73       J74          1.6404   11.90  12.0442   33.05  13.5870 -149.44   UN7    UN7
J74       J73          1.6404   11.90  12.0442   33.05  13.5870 -149.44
J74       JT7          1.6404   11.90  12.0447   33.05  13.5875 -149.44   UN7    UN7
JT7       J74          1.6404   11.90  12.0447   33.05  13.5875 -149.44

B78       JT8          2.8498 -158.50   3.0229   77.84   2.7768  -43.48   UNE    UN8
JT8       B78          2.9127 -129.42   2.8450  105.82   2.6699  -10.52
J83       SE8          0.0000   30.00   0.0000   30.00   0.0000   30.00   UN8    UN8
SE8       J83          0.0000   30.00   0.0000   30.00   0.0000   30.00
PT3       PT3A         0.0000   30.00   0.0000   30.00   0.0000   30.00   PT     PT
PT3A      PT3          0.0104  126.53   0.0104  126.53   0.0104  126.54

PT3A      J73          0.0104  126.53   0.0104  126.53   0.0104  126.54   PT     UN7
J73       PT3A         0.0104  126.53   0.0104  126.53   0.0104  126.54
PT3A      DELTA        0.0000   30.00   0.0000   30.00   0.0000   30.00   PT     PT
DELTA     PT3A         0.0000   30.00   0.0000   30.00   0.0000   30.00
JB78      B78         10.9887 -158.32   3.3721 -162.18  14.3549   20.78          UNE
B78       JB78        10.9887 -158.32   3.3721 -162.18  14.3549   20.78

MAIN00    JJB78       10.9851 -158.37   3.3657 -162.05  14.3454   20.77   UNE
JJB78     MAIN00      10.9851 -158.37   3.3657 -162.05  14.3454   20.77
JJB78     JB78        10.9867 -158.34   3.3685 -162.11  14.3497   20.77
JB78      JJB78       10.9867 -158.34   3.3685 -162.11  14.3497   20.77
3GEN7     GEN7         2.6314   22.68   8.5484 -129.98   6.3261   61.02   UN7    UN7
GEN7      3GEN7        2.6314   22.68   8.5484 -129.98   6.3261   61.02

GEN7      J72          1.6489   11.23  12.0436   33.02  13.5852 -149.42   UN7    UN7
J72       GEN7         1.6489   11.23  12.0436   33.02  13.5852 -149.42


SUBSTATION/S FEEDINGS CURRENTS
-------------------------------

      BUSBAR             RED  PHASE      YELLOW  PHASE      BLUE  PHASE

  FROM        TO       MAG(PU)  ANG(DEG)  MAG(PU)  ANG(DEG)  MAG(PU)  ANG(DEG)

3GEN7     GEN7         2.6314   22.68   8.5484 -129.98   6.3261   61.02
GEN7      3GEN7        2.6314   22.68   8.5484 -129.98   6.3261   61.02
GEN7      J72          1.6489   11.23  12.0436   33.02  13.5852 -149.42
J72       GEN7         1.6489   11.23  12.0436   33.02  13.5852 -149.42
```

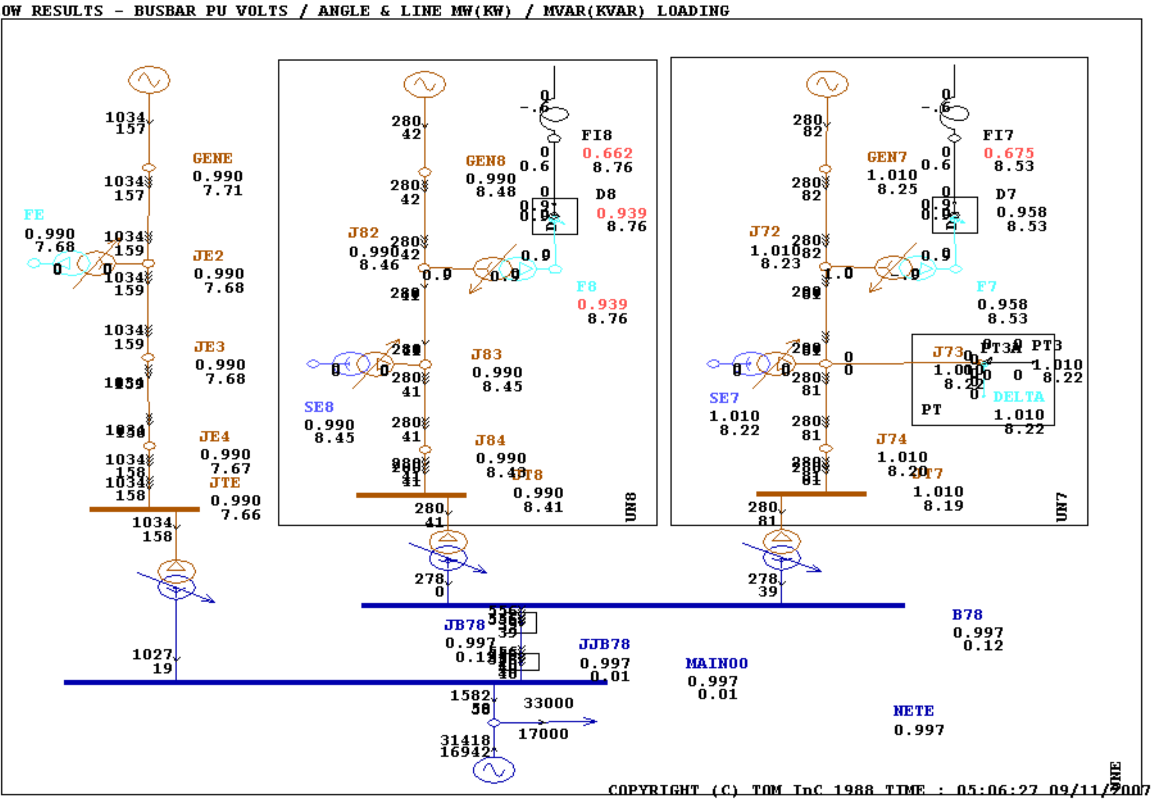
Table AIII.3, shows the result of the fault study when R phase in slot 127 is connected to the T phase in slot 126 (R to the neutral point). According to the section 5 this fault is not the initial two phase fault.

```
UNBALANCED FAULT STUDY RESULTS
 ==============================

 SYSTEM TITLE : X 3GENERATOR
 STUDY  TITLE :
 FAULT IMPEDANCE  (R AND X) =   0.0000   0.0000 PU

 TIME AFTER FAULT INCIDENCE =      0.00 MSEC

 LINE TO LINE

-INTERNAL FAULT IN GENERATOR
 ---------------------------
  WINDING PERCENT FROM TERMINAL

  PHASE B:   0.      PHASE C: 100.

                         RED PHASE      YELLOW PHASE      BLUE PHASE

                      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)
  NEUTRAL SIDE        12.0325 -143.20  28.0628   36.62  16.0305 -143.51
  TERMINAL SIDE       12.0325 -143.20  12.1212 -143.18  24.1537   36.81

-B U S B A R   AC   V O L T A G E S
 ----------------------------------

 BUSBAR          RED  PHASE        YELLOW  PHASE          BLUE  PHASE                  PHASE TO PHASE       AREA
             MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)    MAG(PU)  ANG(DEG)      MAG(PU)    MAG(PU)    MAG(PU)

 3GEN7         0.885    56.362      0.875  -110.287      0.205   155.989         1.009      0.526      0.544   UN7
 J72           0.885    56.363      0.875  -110.302      0.205   155.955         1.009      0.526      0.543   UN7
 J73           0.885    56.305      0.875  -110.258      0.206   155.928         1.009      0.526      0.544   UN7
 J74           0.885    56.248      0.875  -110.214      0.208   155.901         1.009      0.527      0.544   UN7
 JT7           0.885    56.191      0.875  -110.170      0.209   155.875         1.009      0.527      0.545   UN7

 PT3           1.009    62.983      0.526   -97.222      0.544  -136.157         0.875      0.206      0.885   PT
 PT3A          0.885    56.305      0.875  -110.258      0.206   155.928         1.009      0.526      0.544   PT
 DELTA         1.009    62.983      0.526   -97.222      0.544  -136.157         0.875      0.206      0.885   PT

 JB78          0.985     1.243      0.999  -120.338      0.968   119.726         1.000      0.983      0.969
 JJB78         0.988     1.073      0.998  -120.392      0.971   119.816         1.001      0.984      0.973
 GEN7          0.885    56.377      0.875  -110.313      0.204   155.961         1.009      0.526      0.543   UN7


 B R A N C H     C U R R E N T S
 ------------------------------- THE DIRECTION OF CURRENTS ARE FROM SENDING TO RECEIVINGS

       BUSBAR             RED PHASE      YELLOW PHASE      BLUE PHASE     AREA-TO-AREA

   FROM       TO      MAG(PU) ANG(DEG) MAG(PU) ANG(DEG) MAG(PU) ANG(DEG)

 J72       J73          8.8331   58.39   6.7112   67.65  15.4945 -117.61   UN7    UN7
 J73       J72          8.8331   58.39   6.7112   67.65  15.4945 -117.61
 J73       J74          8.8333   58.39   6.7113   67.65  15.4948 -117.61   UN7    UN7
 J74       J73          8.8333   58.39   6.7113   67.65  15.4948 -117.61
 J74       JT7          8.8334   58.39   6.7112   67.65  15.4948 -117.61   UN7    UN7
 JT7       J74          8.8334   58.39   6.7112   67.65  15.4948 -117.61

 MAIN00    NETE        19.4671 -149.62  12.0999   48.07   8.7500    5.52
 MAIN00    JTE          8.7022 -162.73   9.1056   77.65   8.9615  -44.77   UNE    UNE
```

```
JTE       MAIN00       8.6598 -131.78   8.9073  106.19   8.5159  -14.25


MAIN00    JJB78       14.0868 -125.51   3.1302   41.24  11.0632   58.21   UNE
JJB78     MAIN00      14.0868 -125.51   3.1302   41.24  11.0632   58.21
JJB78     JB78        14.0918 -125.50   3.1281   41.35  11.0687   58.19
JB78      JJB78       14.0918 -125.50   3.1281   41.35  11.0687   58.19
3GEN7     GEN7         3.5429  -91.65   5.4121 -114.31   8.7882   74.63   UN7    UN7
GEN7      3GEN7        3.5429  -91.65   5.4121 -114.31   8.7882   74.63

GEN7      J72          8.8329   58.31   6.7110   67.75  15.4922 -117.61   UN7    UN7
J72       GEN7         8.8329   58.31   6.7110   67.75  15.4922 -117.61


SUBSTATION/S FEEDINGS CURRENTS
-------------------------------

      BUSBAR              RED PHASE      YELLOW PHASE      BLUE PHASE

  FROM        TO       MAG(PU)  ANG(DEG)  MAG(PU)  ANG(DEG)  MAG(PU)  ANG(DEG)

3GEN7     GEN7         3.5429  -91.65   5.4121 -114.31   8.7882   74.63
GEN7      3GEN7        3.5429  -91.65   5.4121 -114.31   8.7882   74.63
GEN7      J72          8.8329   58.31   6.7110   67.75  15.4922 -117.61
J72       GEN7         8.8329   58.31   6.7110   67.75  15.4922 -117.61
```

Figure AIII.5 shows the flow of 3I0 for LG faults with introducing the ferroresonance effect, due to the lose earth connection in the secondary side. The fault is located in J72 for flows clarity.

LOAD FLOW RESULTS - BUSBAR PU VOLTS / ANGLE & LINE MW(KW) / MVAR(KVAR) LOADING



III.3 THE RECORDED FAULT CURRENTS AND VOLTAGES

Figure 2 shows the waveforms of the recorded fault currents and voltages. The following magnitude can be brought under consideration:

Phasor of Vst after the two phase fault is approximately: 0.83 P.U.

Phasor of Vtr after the two phase fault is approximately 0.26 P.U.

Phasor of Vrs after the two phase fault is approximately 0.84 P.U.

Phasor of Ir after the two phase fault is approximately 3.6 P.U.

Phasor of Is after the two phase fault is approximately 0.829 P.U.

Phasor of It after the two phase fault is approximately 2.93 P.U.

P.U. base is 15.75KV for voltages and 12500 A for currents.

III.4 INTERPRETATION OF THE RESULTS:

Comparing the results obtained in the previous two sections, will give a clear insight of the fault situation and the magnitudes of the currents as the followings:

(1) A two phase fault occurred between the slots 326 and 327 while the single phase fault in slot 217 was presented. The double phase fault had a fault impedance of approximately 0.01 P.U. inductive (based used in section III.2) and the single phase fault had an impedance of approximately 0.005 P.U. resistive.

(2) The double phase faults in slot 126, and 127 have not occurred till the interruption of the phase T.

(3) The magnitude of the currents is as the followings:

Coming from the source side: 48KA in R phase, 46KA in T phase

The differential relay sees: (the values are read from Table III.2

For R phase (6.327<61.02-7.7785<-170.32)-13.59<-149.42 = (12.73<32.52)-13.08<-149.34=26.31p.u.BASE 3670 A

On 12500A*0.771 is 10.02In as shown by differential relay

For T phase (8.549<-129.98-6.7126<9.58)-12.045<33.03 = 26.38p.u. BASE 3670A on 12500*0.771 is 10.05In

For S phase (2.6315<22.67-1.0663<10.33)-1.648<11.31) = 0.55p.u. BASE 3670A on 12500*0.771 is 0.24 In

We did not consider DC decays in all the calculation and the relay has a psequ RMS values while here is the actual RMS. It is worth to mention that the difference of the current in unfaulted phase (i.e. phase S) is due to the mutual influence of the faulted phases in generator internal fault.

Other fault and three phase transient stability (runs) studies (not reported in this document) are all show that the above conclusion would be the best we may reach.

APPENDIX IV

GENERATOTR MODELLING FOR FIELD TRANSIENTS

The mathematical representations of the generator model have been widely used as the basic for time domain simulation [5]. A block diagram transfer function model of the generator is represented in here to simulate the behaviour of the field variables during the transients. Figure AIV.1 shows the generator field components. What it is intended in this section, is to simulate the opening of the field under two phases fault condition, in order to find out the transients involved.

IV.1 GENERATOR MODELING

The d-q model of a synchronous generator is represented in the following equations. The equations can be found in many literatures including [1], and [2].

$$Vd = -rId - \lambda' d - \omega\lambda q$$

$$Vq = -rIq - \lambda' q + \omega\lambda d$$

$$Vf = -rfIf - \lambda' f$$

$$0 = -rkdIkd - \lambda' kd$$

$$0 = -rkqIkq - \lambda' kq$$

$$\lambda d - \lambda AD = ldId$$

$$\lambda q - \lambda AQ = lqIq$$

$$\lambda f - \lambda AD = lfIf$$

$$\lambda kd - \lambda AD = lkdIkd$$

$$\lambda kq - \lambda AQ = lkqIkq$$

$$\lambda AD = LAD(Id + If + Ikd) = LMD(\lambda d / ld + \lambda f / lf + \lambda kd / lkd)$$

$$\lambda AQ = LAQ(Iq + Ikq) = LMQ(\lambda q / lq + \lambda kq / lkq)$$

$$1/LMD = 1/ld + 1/lf + 1/lkd + 1/LAD$$

$$1/LMQ = 1/lq + 1/lkd + 1/LAQ$$

The following base quantities are used:

Stator Base Quantities: In the equations

$Sbase = 263/3MVA$

$Vbase = 15.75KV/1.732$

$Ibase = 9641A$

$Zbase = 0.943Ohm$

$Wbase = 314.1516Rad/Sec$

$Lbase = 3.0mH$

Rotor Base Quantities are:

$Sfbase = 87.7MVA$

$Vfbase = 176KV$

$Ifbase = 498.1A$

$Zfbase = 353.34Ohm$

$Lfbase = 1.124H$

$Cfbase = 0.125\mu F$

$Yfbase = 0.004\sigma hm$

The following parameters in P.U. can be derived [1] from machine sub transient and transient data which are written in input data list:

$r = 0.0025$

$ld = lq = 0.191$

$LAD = 1.065 - 0.191 = 0.874$

$LAQ = 0.656 - 0.191 = 0.465$

$lf = 0.062$

$lkd = 0.12$

$lkq = 0.0426$

$Lf = 0.936$

$Lkd = 0.993$

$Lkq = 0.5076$

$rf = 0.000281 * effect - of - heating$

$rkd = 0.0121$

$LMD = 0.0324$

$LMQ = 0.135$

$rkq = 0.06$

IV.1.1 Field discharge resistor

A 1300V, 6750A, 3564KJ, nonlinear resistor is used in the field to discharge the field current and prevent the overvoltages of the field breaking.

Document M26412A/02 shows the V-I characteristic of this nonlinear resistor. The following relationship can be extracted from this logarithmic characteristic:

AC waveforms:

$$IR = 0.0000032 * Vf^{3}\, Amper - Volt$$

$$IR = 13{,}162{,}300.4 * Vf^{3}\, P.U.$$

DC waveforms:

$$IR = 0.000000450832 * Vf^{2.7}\, Amper - Volt$$

$$IR = 5{,}458{,}278.9 * Vf^{2.7}\, P.U.$$

IV.1.1 Field capacitance

A capacitance exists between any two conductors or a conductor and the earth or a conductor and a charged/neutralized plate.

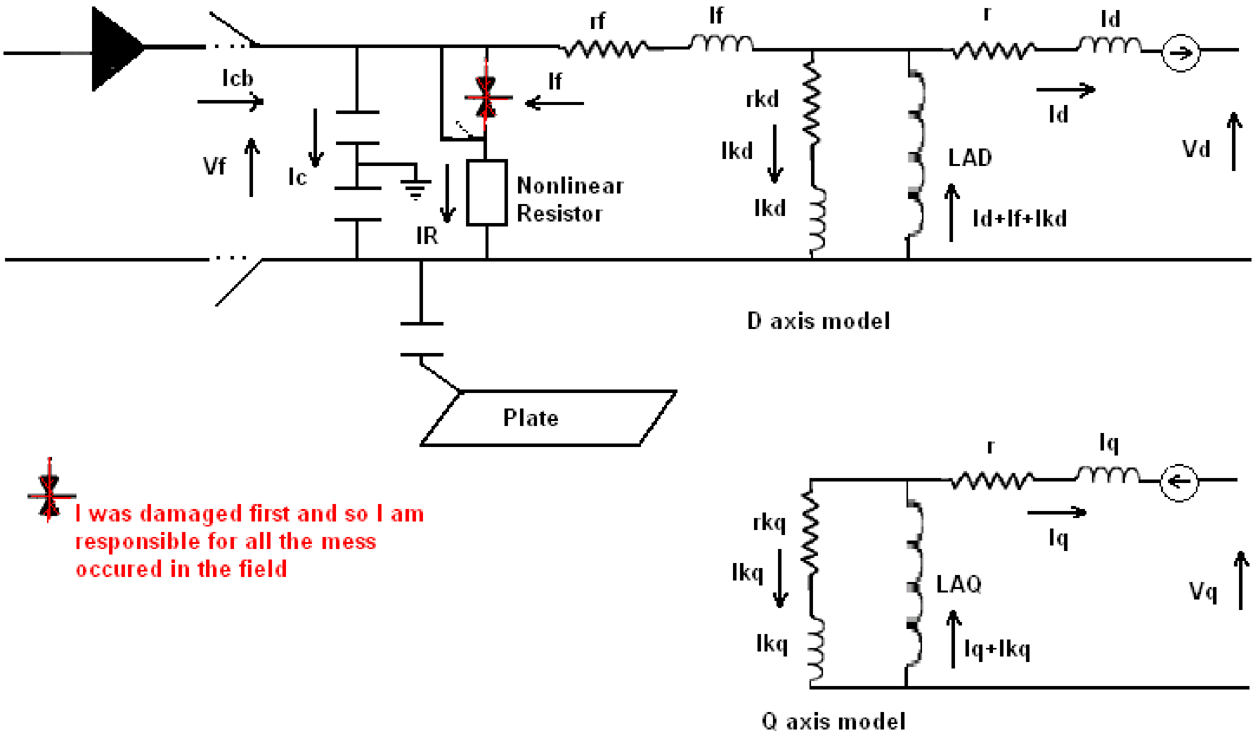
The field circuit capacitance magnitude between the positive and negative conductors can be extracted from generator open circuit tests – field discharge tests in emergency mode.

The following relationship applies: where 1/C is equal 0.25 P.U.

$$Icb = IR + IC - If$$

$$Vf = 1 \backslash C \int Icdt$$

Figure AIV.1 Field circuit schematic

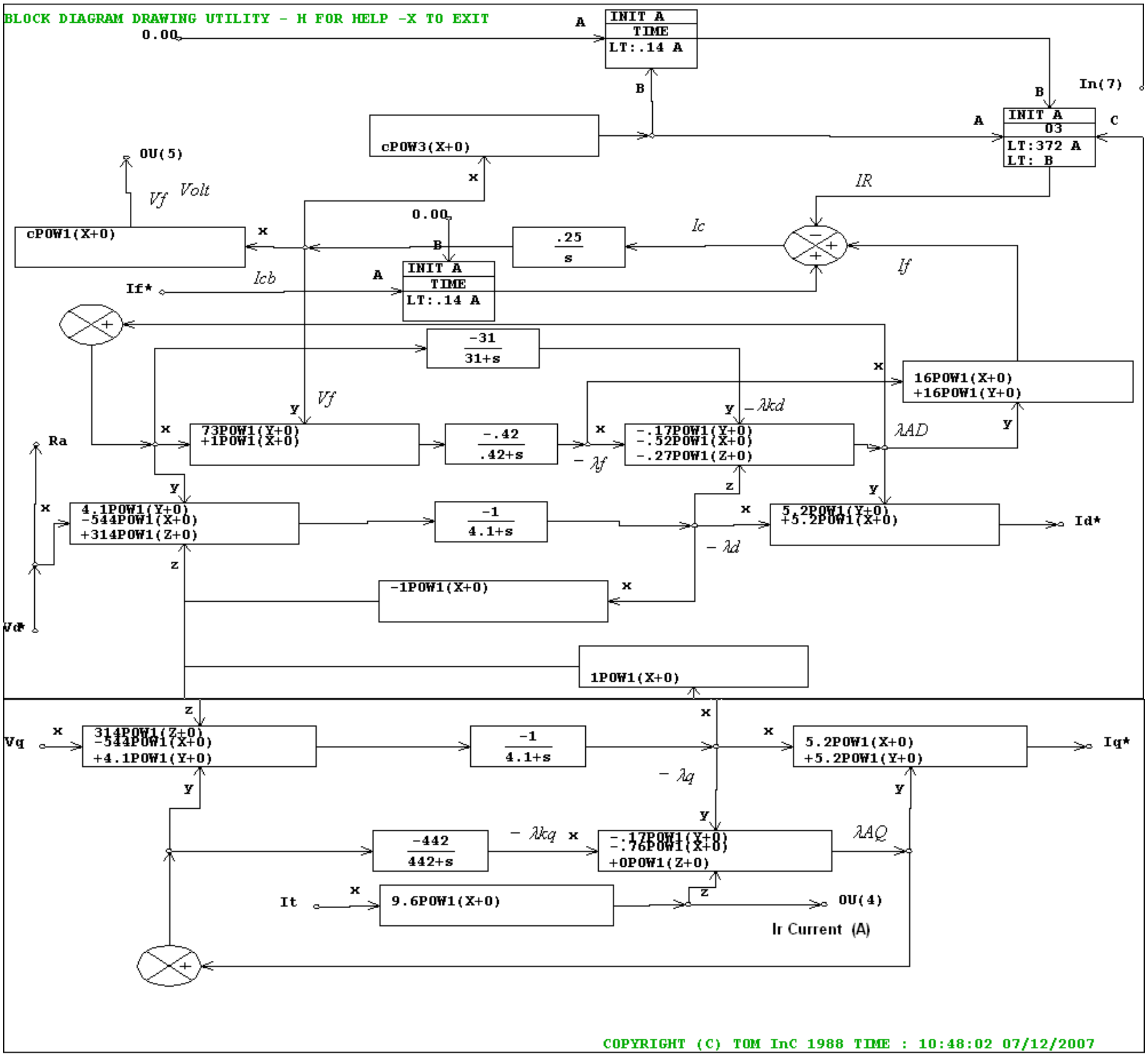


I was damaged first and so I am responsible for all the mess occured in the field

IV.1.3 Block diagram transfer function model

A block diagram transfer function model of the above equations is constructed using UDEM (User Defined Equipment Modelling) of PASHA program. Logical switch elements are used to simulate the switching behaviour of the field and omit those equations not needed during the simulation. The block diagram transfer function constructed is shown in figures AIV.2.

Figure AIV.2 block diagram transfer function model of the generator and its field:



IV.2 Testing the generator model

1) The generator is subjected to a three phase fault in PASHA fault analysis when generator is operating at no load condition with the terminal voltage of 0.4917. This test has been done to be ensured about the actual plant test results.

Generator UDEM model shown in figure AIV.2 is subjected to the following tests:

2) Field opening in emergency shut down mode, when generator is operating at no load condition with the terminal voltage of 1.0 P.U.
3) Short circuit test, again the generator is operating in no load condition, with terminal voltage of 0.4917

The result of dynamic fault analysis for case 1 is shown in figure IV.3. The results of case 2 above are shown in Figures AIV.4 and AIV.5. The results of the site tests for the above cases are shown in Figures AIV.6, and AIV.7. The results are in close agreement; therefore, the generator model is valid, however, some might notice that the magnitude of the overvoltage written for fault opening is not correct when the generator was in the site test.

IV.3 Opening the field under full load

Having a correct model, for field opening, figure AIV.8, shows the interruption of the field under full load condition. The overvoltage arise in the field will go to 790V.

IV.3 Opening the field under fault condition

Figure AIV.9 shows the results of three phase fault of the generator without field opening in the full load condition, the amount of field overvoltage is 1192V.

Figures AIV.10 and AIV.11 show the same results while the controlling diodes of the discharging resistor are damaged when the voltage goes above 1100V, and after some milliseconds the field has been opened by field circuit breaker (and so resistor came in). The amount of overvoltage depends to the magnitude of field current when the field circuit breaker interrupts the circuits involved. Here, for some examples it is between 9 to 10KV.

IV.4 Opening the field under two phase fault condition

D-q model of the generator is valid for balanced operation or three phase fault studies. However, if the current of the unfaulted phase is ignored, it will be valid under two phase fault too.

Figure AIV.12 shows the same situation for fault opening as figure AIV.10 when two phase fault are applied.

IV.5 sub-conclusion

In conclusion the controlling diodes of the field are mostly responsible for the damages came inside the field, because of high overvoltages around 10KV between two poles and around 5KV respect to ground.

In the actual situation of the events as described in section 5, this overvoltage has produced an arc between the field circuit breaker and the plates around the field circuits. One picture is shown in Figure 2. The same overvoltage damaged the field winding number 25.

The high magnitude overvoltage at the other side of the field circuit breaker is passed through the field circuit breaker. This overvoltage caused the thyristors and their controllers to be damages. The damages of the thyristors might also be because of the earth arc into the cabinet as described in Elin reports. The important point is that; from this instant of time the excitation transformer is short circuited in the secondary thought Thyristor Bridge.

Figure AIV.13 shows the thyristors which are damages.

Figure AVI.3(a) Three phase fault in PASHA fault analysis when generator is operating at no load condition with the terminal voltage of 0.4917. This is done in order to get ensure about the test results. Saturation is considered.

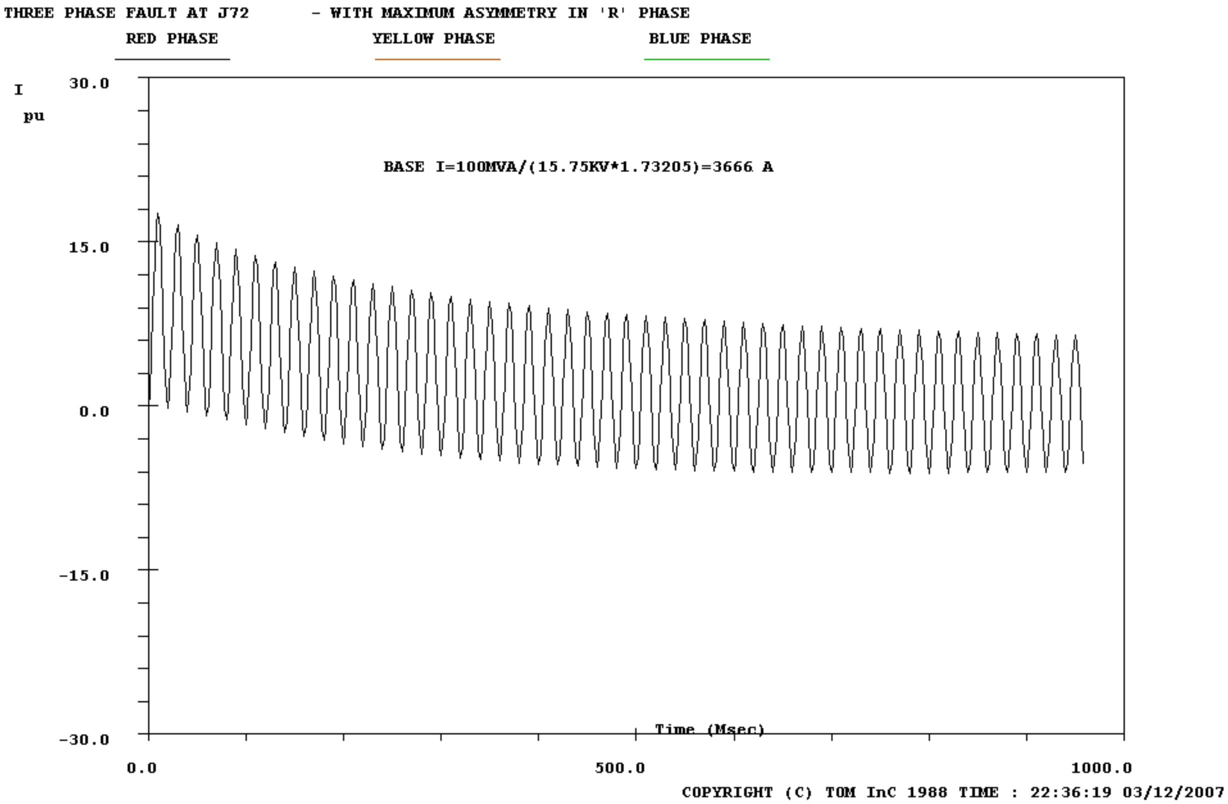


Figure AVI.3(b) Three phase fault in PASHA fault analysis when generator is operating at no load condition with the terminal voltage of 0.4917. This is done in order to get ensure about the test results. Without saturation, base as figure AVI.3 (a)

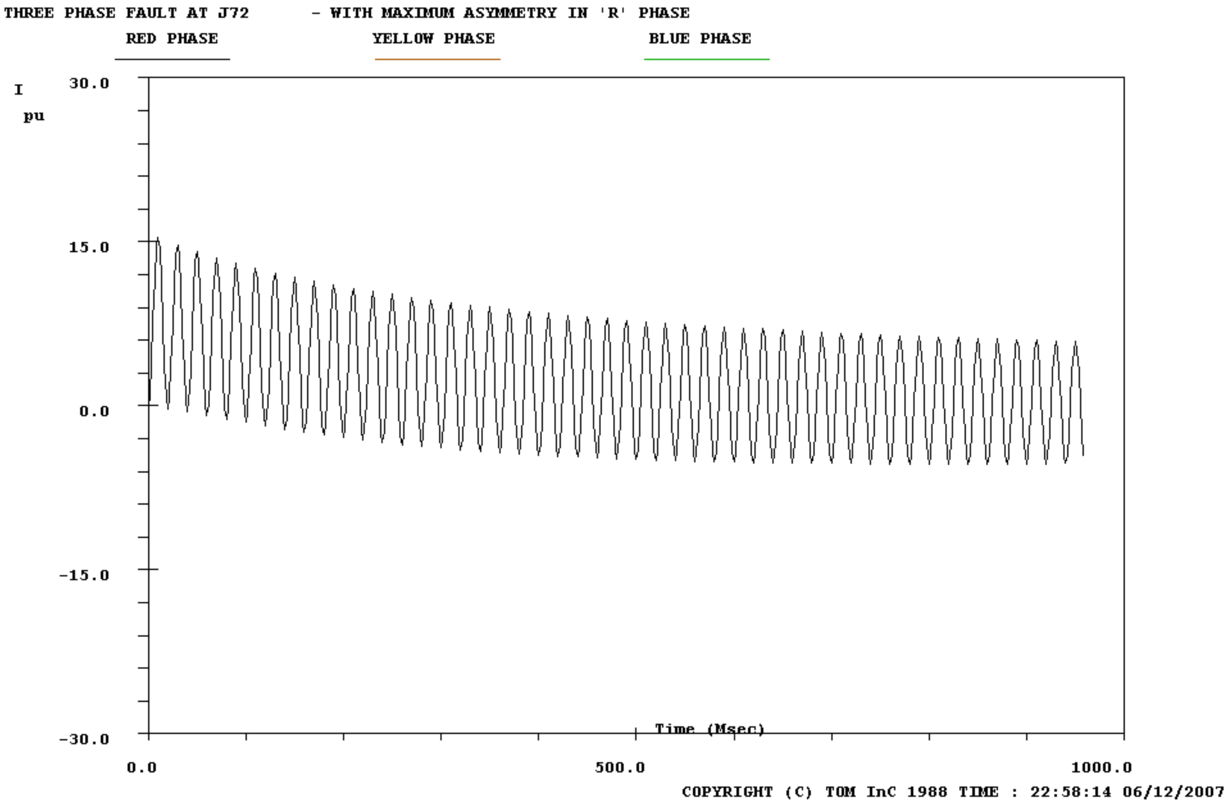
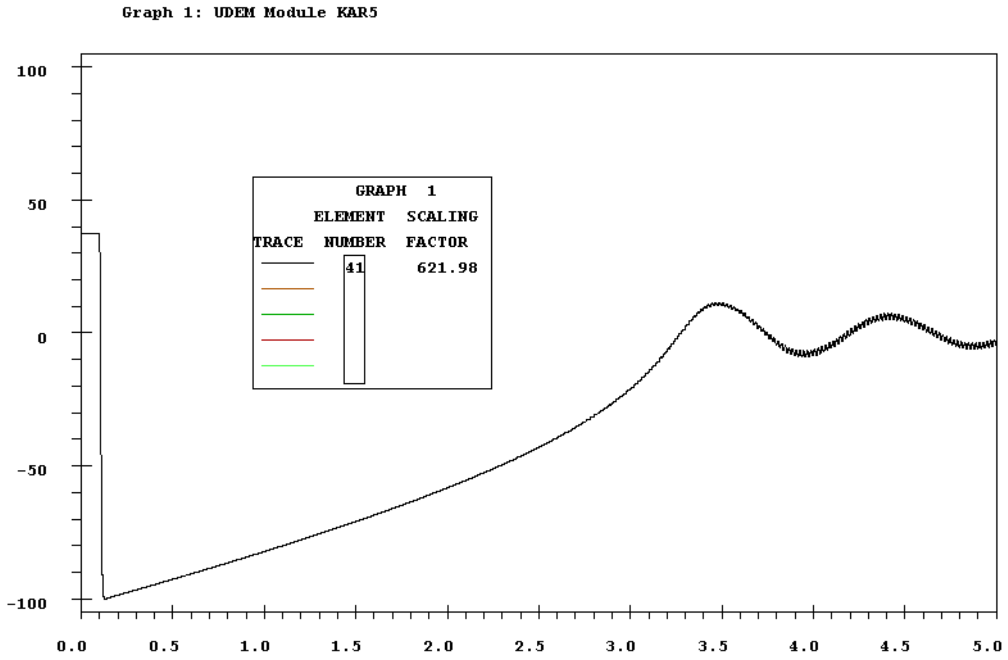


Figure AIV.4 simulation results, emergency opening of the field circuit breaker, field voltage (V)

```
UDEM PLOT OF ELEMENT OUTPUTS IN (%)
```



```
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```
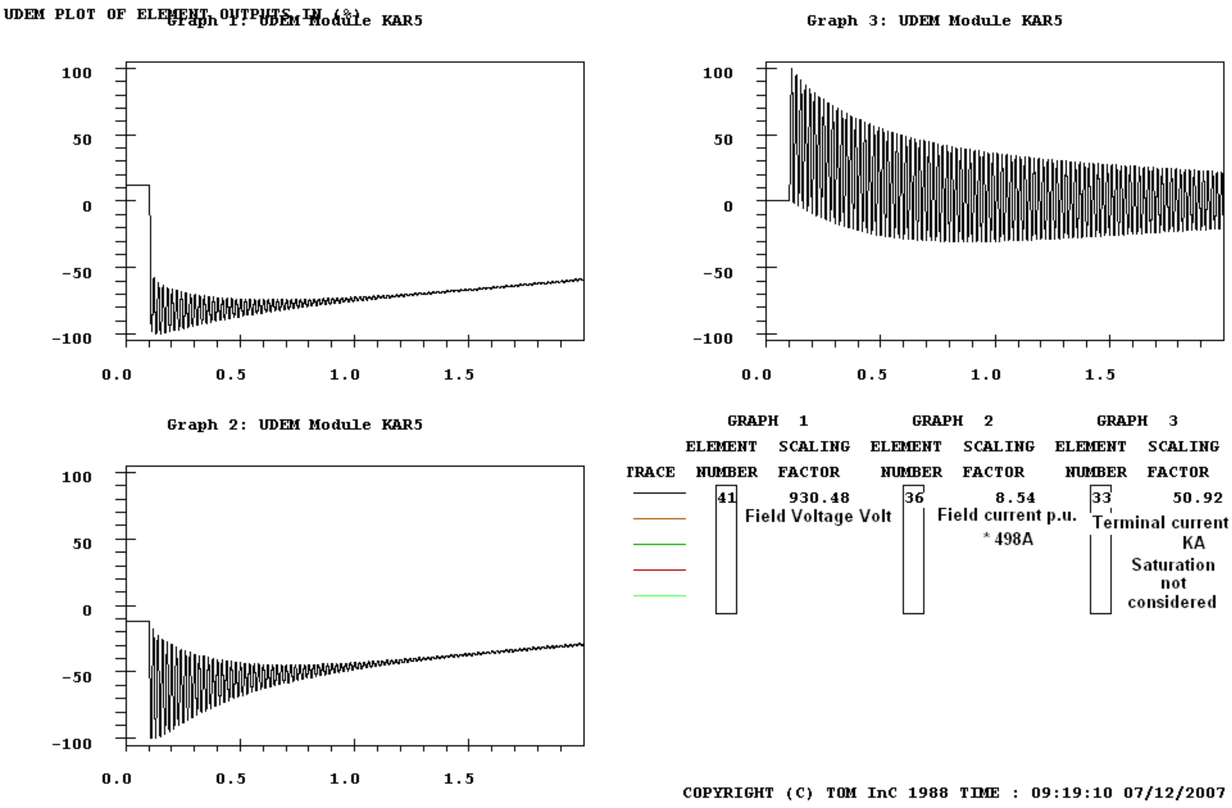

Figure AIV.5 simulation results, three phase short circuit of the stator, generator was operating at no load condition with 0.4917 terminal voltages. Saturation is not considered, if wants, multiply the terminal current values on 0.23/0.2.



UDEM PLOT OF ELEMENT OUTPUTS IN (%)

Graph 1: UDEM Module KAR5

Graph 3: UDEM Module KAR5

Graph 2: UDEM Module KAR5

TRACE	GRAPH 1 ELEMENT NUMBER	GRAPH 1 SCALING FACTOR	GRAPH 2 ELEMENT NUMBER	GRAPH 2 SCALING FACTOR	GRAPH 3 ELEMENT NUMBER	GRAPH 3 SCALING FACTOR
———	41	930.48 Field Voltage Volt	36	8.54 Field current p.u. * 498A	33	50.92 Terminal current KA Saturation not considered

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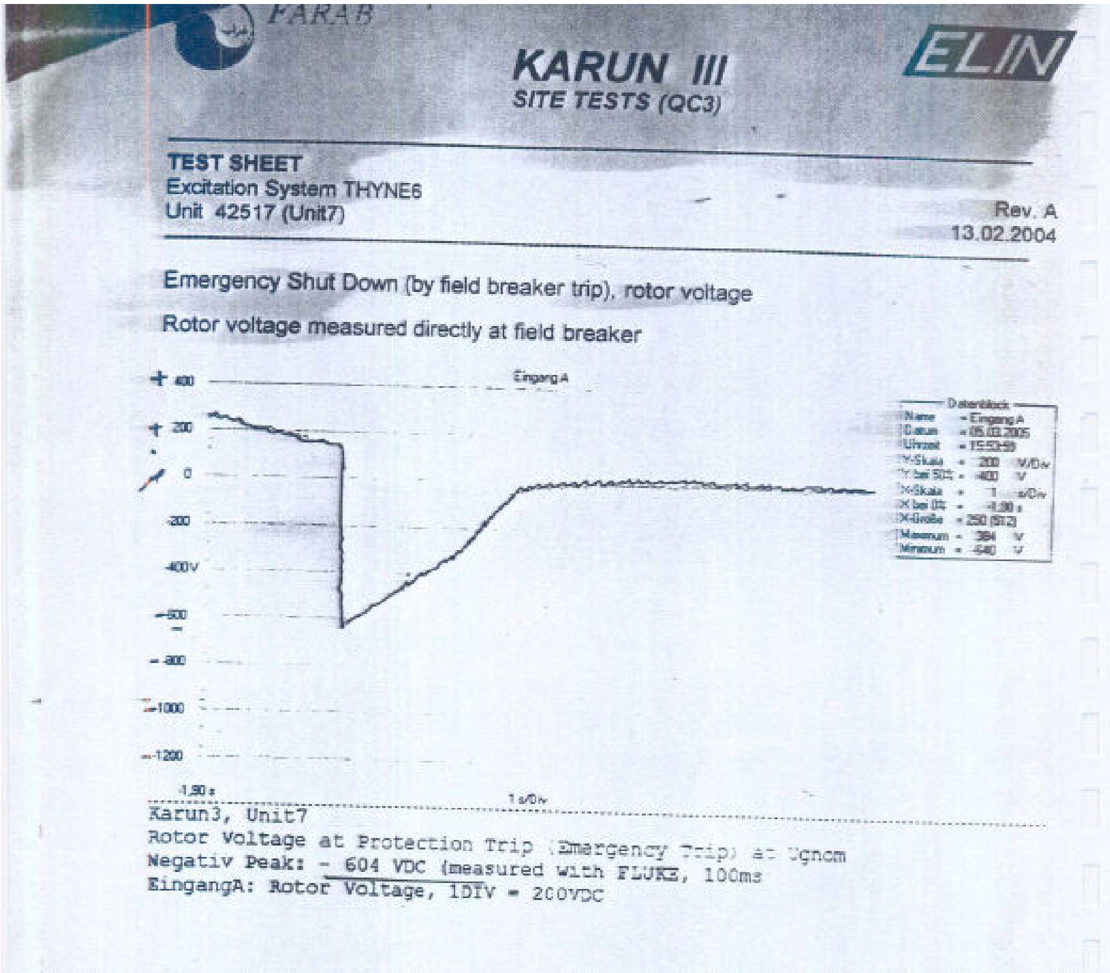
Figure AIV.6 actual test results, emergency opening of the field circuit breaker



FARAB

ELIN

KARUN III

SITE TESTS (QC3)

TEST SHEET

Excitation System THYNE6

Unit 42517 (Unit7)

Rev. A

13.02.2004

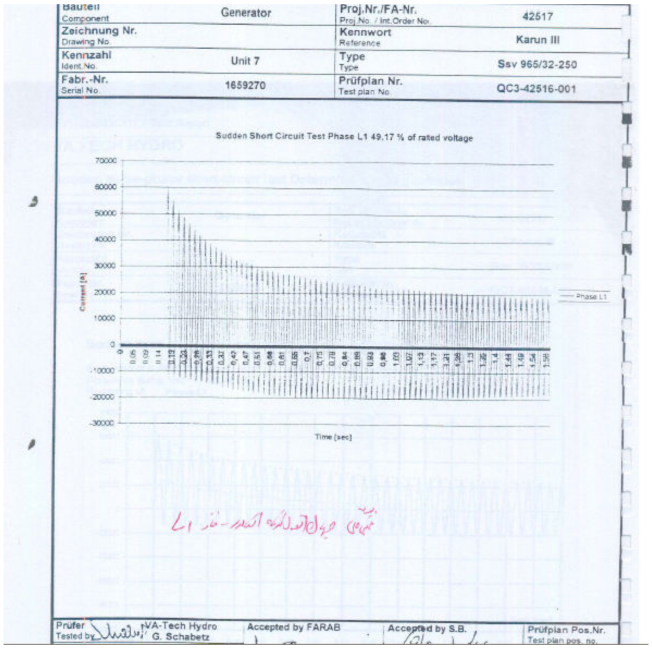
Emergency Shut Down (by field breaker trip), rotor voltage

Rotor voltage measured directly at field breaker

Datenblock
Name = EingangA
Datum = 05.03.2005
Uhrzeit = 15:53:59
Y-Skala = 200 V/Div
Y bei 50% = -400 V
X-Skala = 1 s/Div
X bei 0% = -1,90 s
X-Größe = 250 (512)
Maximum = 384 V
Minimum = -640 V

```
Karun3, Unit7
Rotor Voltage at Protection Trip (Emergency Trip) at Ugnom
Negativ Peak: - 604 VDC (measured with FLUKE, 100ms
EingangA: Rotor Voltage, 1DIV = 200VDC
```

Figure AIV.7 actual test results, three phase short circuit of the stator, generator was operating in no load condition with 0.4917 terminal voltages

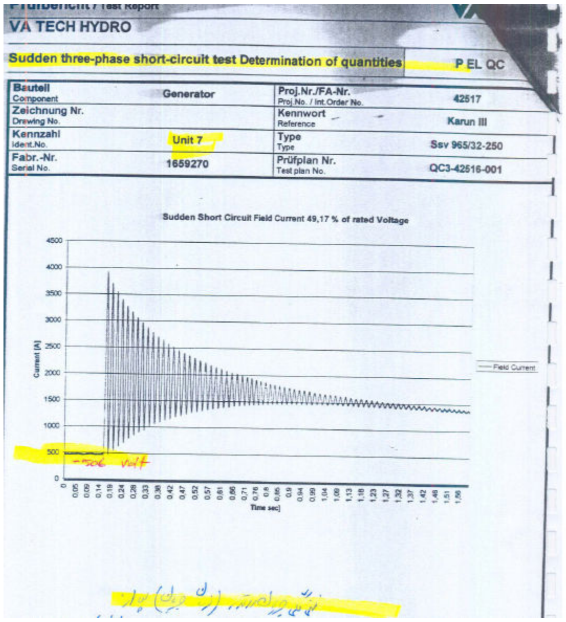


Bauteil Component	Generator	Proj.Nr./FA-Nr. Proj.No. / Int.Order No.	42517
Zeichnung Nr. Drawing No.		Kennwort Reference	Karun III
Kennzahl Ident.No.	Unit 7	Type Type	Ssv 965/32-250
Fabr.-Nr. Serial No.	1659270	Prüfplan Nr. Test plan No.	QC3-42516-001

Sudden Short Circuit Test Phase L1 49,17 % of rated voltage

منحنی جریان اتصال کوتاه استاتور - فاز L1

Prüfer Tested by	VA-Tech Hydro G. Schabetz	Accepted by FARAB	Accepted by S.B.	Prüfplan Pos.Nr. Test plan pos. no.



Prüfbericht / Test Report

VA TECH HYDRO

Sudden three-phase short-circuit test Determination of quantities — P EL QC

Bauteil Component	Generator	Proj.Nr./FA-Nr. Proj.No. / Int.Order No.	42517
Zeichnung Nr. Drawing No.		Kennwort Reference	Karun III
Kennzahl Ident.No.	Unit 7	Type Type	Ssv 965/32-250
Fabr.-Nr. Serial No.	1659270	Prüfplan Nr. Test plan No.	QC3-42516-001

Sudden Short Circuit Field Current 49,17 % of rated Voltage

~506 volt

[illegible]

Figure AIV.8; simulation result of emergency field opening under full load condition

UDEM PLOT OF ELEMENT OUTPUTS IN (%)

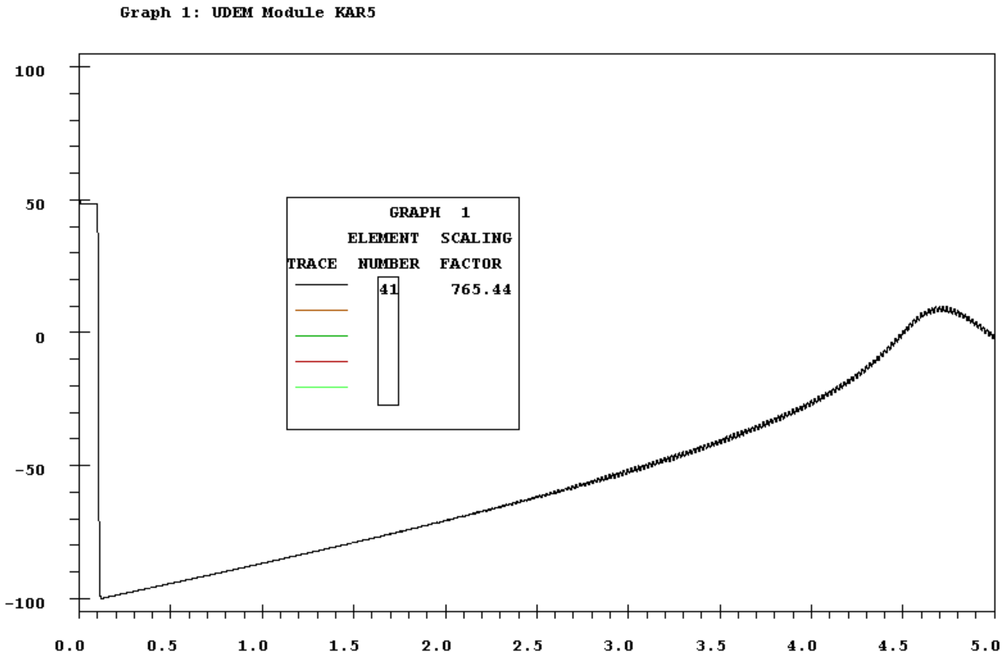


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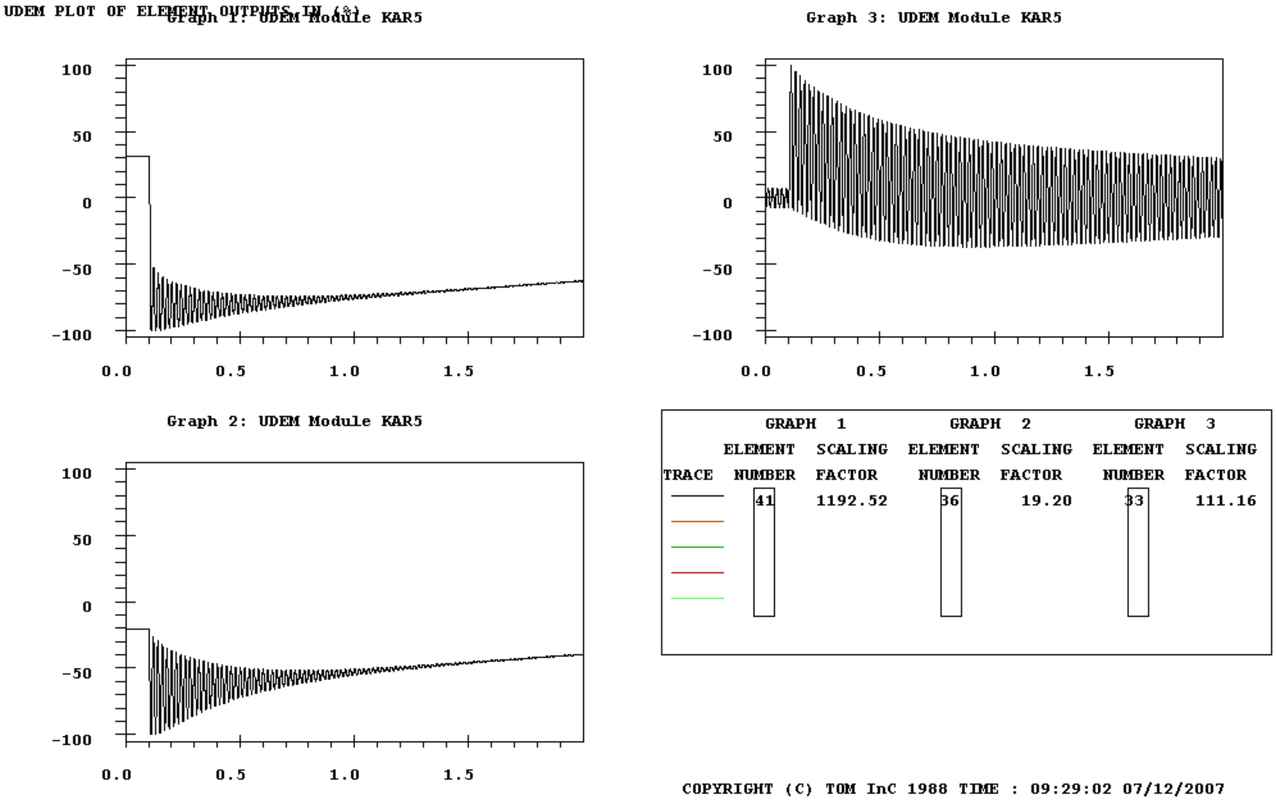
Figure AIV.9 simulation results, three phase short circuit of the stator, generator was operating at full load condition with 1.0P.U. terminal voltages. Saturation is not considered, if wants, multiply the terminal current values on 0.23/0.2.



TRACE	GRAPH 1 ELEMENT NUMBER	GRAPH 1 SCALING FACTOR	GRAPH 2 ELEMENT NUMBER	GRAPH 2 SCALING FACTOR	GRAPH 3 ELEMENT NUMBER	GRAPH 3 SCALING FACTOR
─	41	1192.52	36	19.20	33	111.16

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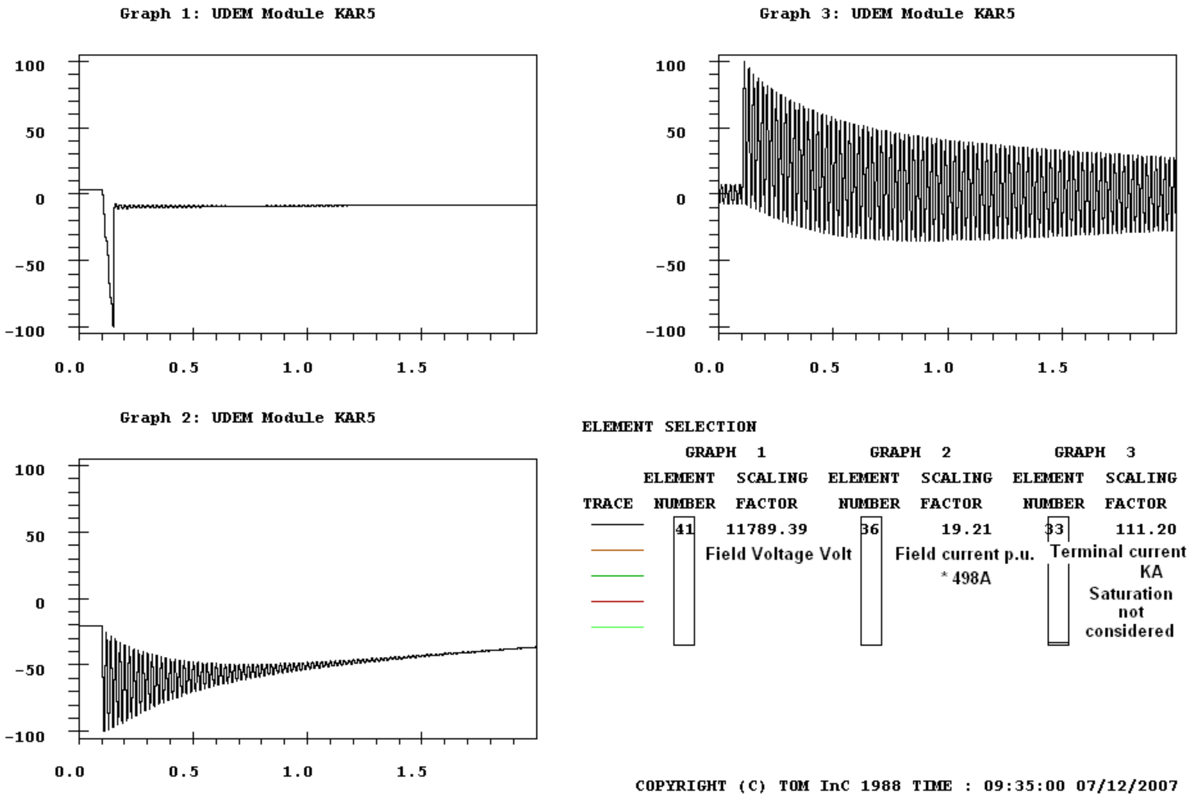
Figure AIV.10 simulation results, three phase short circuit of the stator, generator was operating at full load condition with 1.0P.U. terminal voltages. Saturation is not considered, if wants, multiply the terminal current values on 0.23/0.2. The controlling diodes are damaged in 0.15 Sec. with 1100V



```
ELEMENT SELECTION
            GRAPH   1               GRAPH   2               GRAPH   3
        ELEMENT  SCALING       ELEMENT  SCALING       ELEMENT  SCALING
TRACE   NUMBER   FACTOR        NUMBER   FACTOR        NUMBER   FACTOR
         41     11789.39        36        19.21        33        111.20
              Field Voltage Volt   Field current p.u.   Terminal current
                                        * 498A                KA
                                                          Saturation
                                                             not
                                                          considered

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```
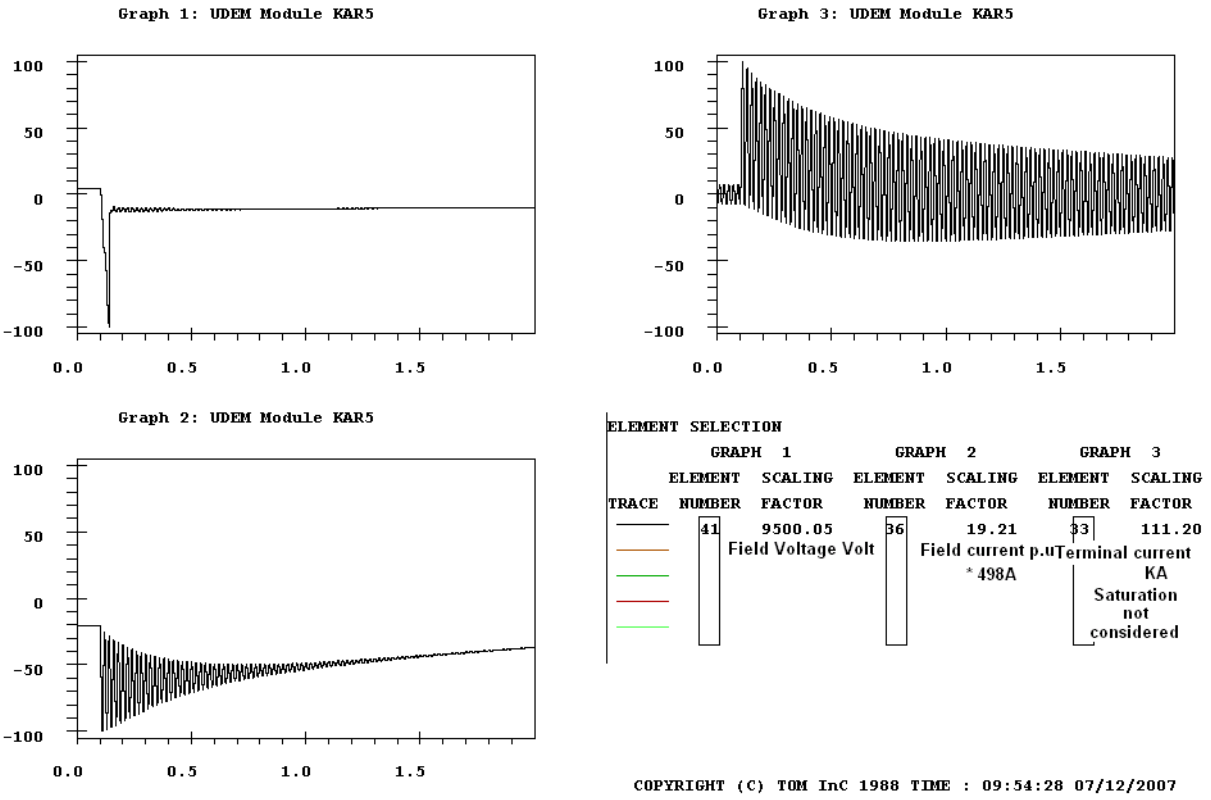

Figure AIV.11 simulation results, three phase short circuit of the stator, generator was operating at full load condition with 1.0P.U. terminal voltages. Saturation is not considered, if wants, multiply the terminal current values on 0.23/0.2. The controlling diodes are damaged in 0.143 Sec. with 1100V



```
ELEMENT SELECTION
            GRAPH  1              GRAPH  2              GRAPH  3
        ELEMENT  SCALING    ELEMENT  SCALING    ELEMENT  SCALING
TRACE   NUMBER   FACTOR     NUMBER   FACTOR     NUMBER   FACTOR
        41       9500.05    36       19.21      33       111.20
        Field Voltage Volt  Field current p.u   Terminal current
                                 * 498A                KA
                                                   Saturation
                                                      not
                                                   considered
```

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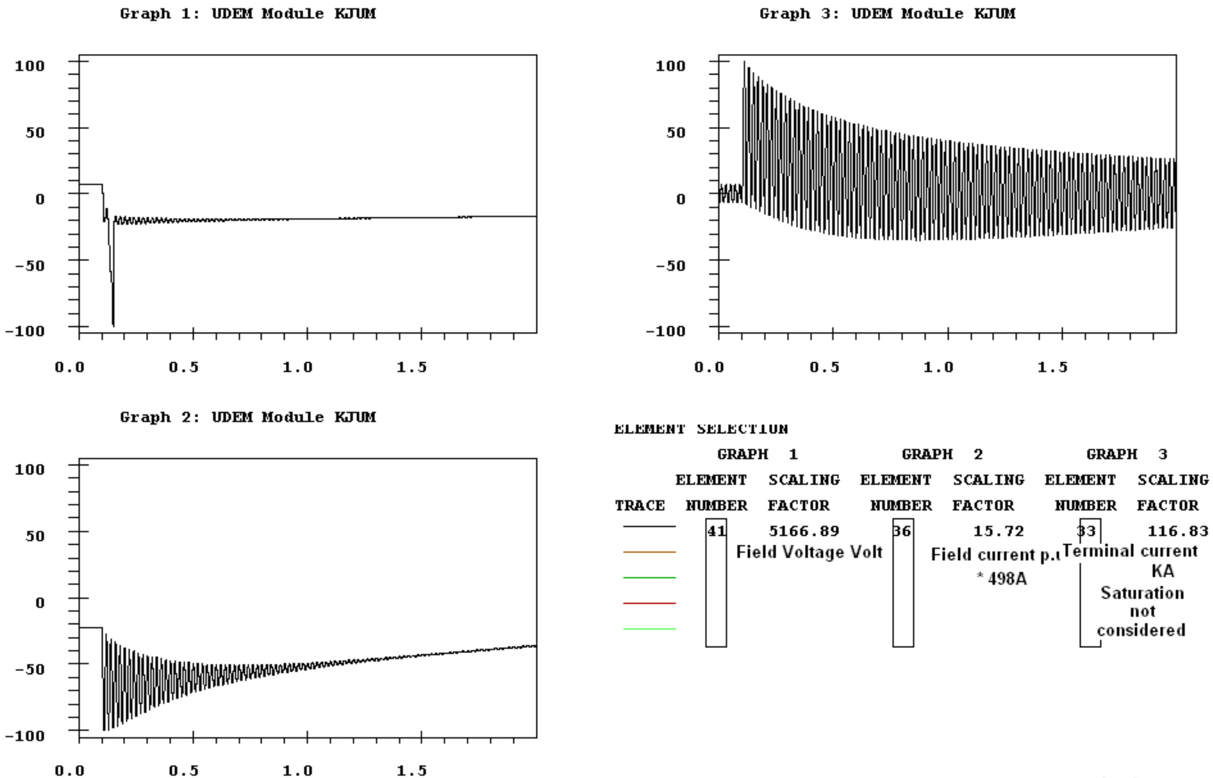
Figure AIV.12 simulation results, two phase short circuit of the stator, generator was operating at full load condition with 1.0P.U. terminal voltages. Saturation is not considered, if wants, multiply the terminal current values on 0.23/0.2. The controlling diodes are damaged in 0.15 Sec. with 1100V and some oscillation during the damage.



```
ELEMENT SELECTION
                  GRAPH   1            GRAPH   2            GRAPH   3
           ELEMENT  SCALING     ELEMENT  SCALING     ELEMENT  SCALING
TRACE      NUMBER   FACTOR      NUMBER   FACTOR      NUMBER   FACTOR
           41       5166.89     36       15.72       33       116.83
                Field Voltage Volt   Field current p.u  Terminal current
                                     * 498A                   KA
                                                          Saturation
                                                             not
                                                          considered
```

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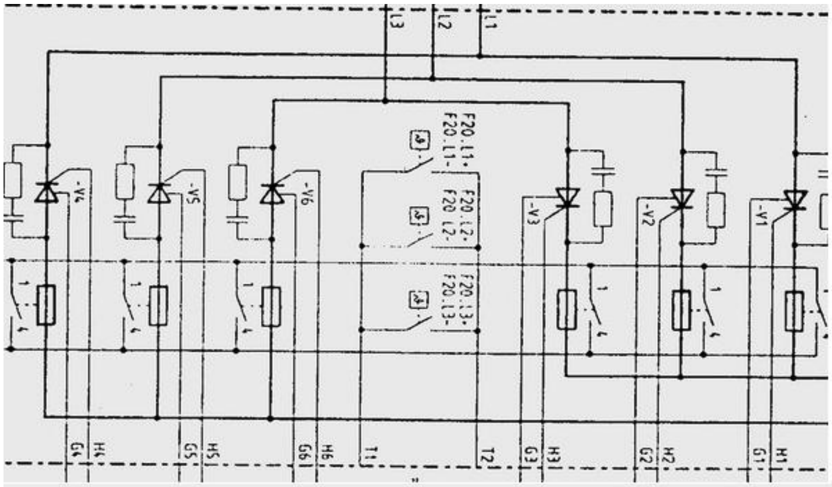
Figure AIV.13 Thyristors damages:



* Thyristors V1, V2, V3, V4, V6 are damaged (shorted)

* Thyristor Fuses L_2+ (V2) and L1- (V4) are damaged!

APPENDIX V

FAST TRANSIENT SWITCHING

Opening an inductive circuit in the presence of capacitance will produce over voltages in many situations [1]. In our case when phase T is opening, since it is already grounded though the single phase fault, there would be no such a transient. But when the phase R is going to be opened by GCB at the instant of current zero the source side voltage would be in its maximum. The ferroresonace of the PT in the source side and the portion of the generator inductance which is already grounded through phase T in the generator side would impose a very difficult duty for GCB to open the fault in current zero. Some restrike may take place and the current chopping would be the consequences.

Figure AV.1 shows a simplified situation of the above opening. Figure AV.2 shows the Red phase current. It seems that in the vicinity of the current zero some current chopping and restrikes have taken place. A clear insight of the restrike cannot be seen in the figures because of CT magnetic delays, but the way that the current is going to zero will show such a condition.

However, without current chopping an overvoltage with the frequency of 13.4KHZ (L2=0.57mH, and C2=0.25 uF) and 15.3 KHZ (L1=0.4mH, and C1=270nF) in the generator side will occur. The magnitude of overvoltage in the generator side would be calculated from the following formula: (please refer to the reference for details)

Vc2 (t) = 1+1.35Cosw1t+2.36Cosw2t, this is shown in figure AV.3

The maximum is about 4.5 P.U.

Therefore, if the current chopping has not been occurred the value is around 57.7KV (4.5*15.75*1.41/1.732) and if chopping of 800 Amper (from the figure this seems to be 3400A) has been made this would be around 54KV (0.5Li**2=0.5Cv**2). Due to distributed nature of the generator capacitance and the mutual effect of the reactances, more elaborate analysis must be done for overvoltages in the vicinity of generators [2], which is out of the scope of this report. Even in this simple analysis we have not considered the back EMF in phase R which is quite out of phase with the source voltage at the instant of opening. This may bring overvoltages to 1.25 times of the values that are just mentioned. For the calculations made please refer to the formula available in section 3.4 of the reference.

The high frequent overvoltage of phase R in the generator side have caused the discharge capacitor of CC2 which was the nearest one to blow up and the other discharge capacitors in this phase for the other windings just to get harmed (because of their distance and the damping effect in the circuits involved). Its current has been passed through grounded faulted point of slot 217 and made the surroundings coppers scattered. It also paths through the nearest earth in the metal cover and brought damages to the outgoing plates. The high frequency shocks had caused the complete destruction of oil mist distracter and its other belongings.

Figure AV.1 Interruption of phase R situation and the faults are in the windings 2U and 3W.

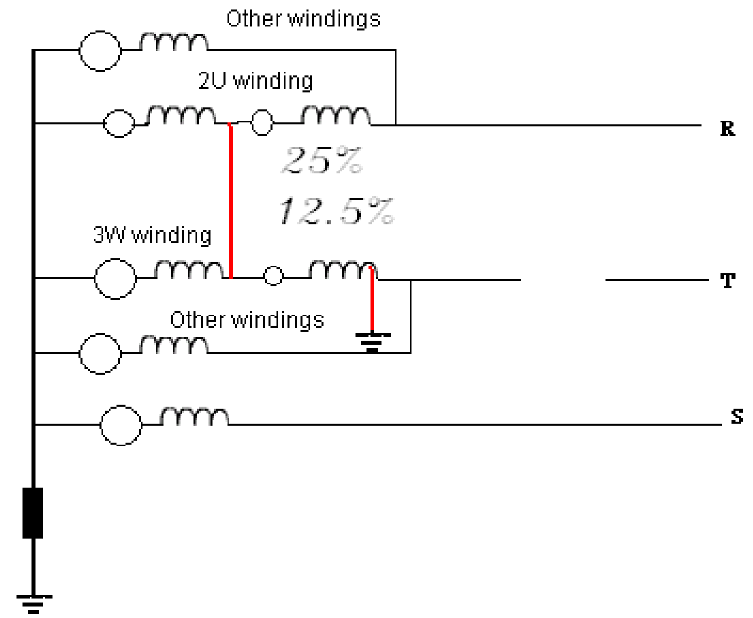


Figure AV.2 Current interruption

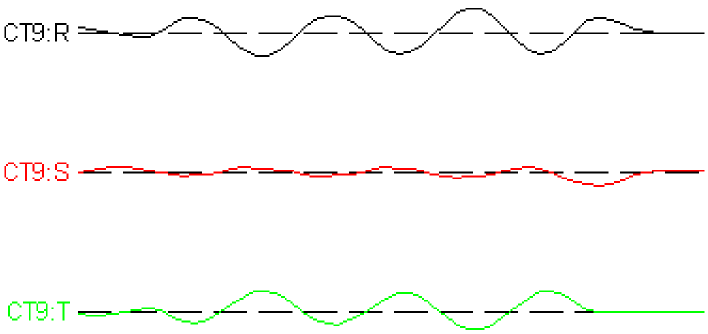
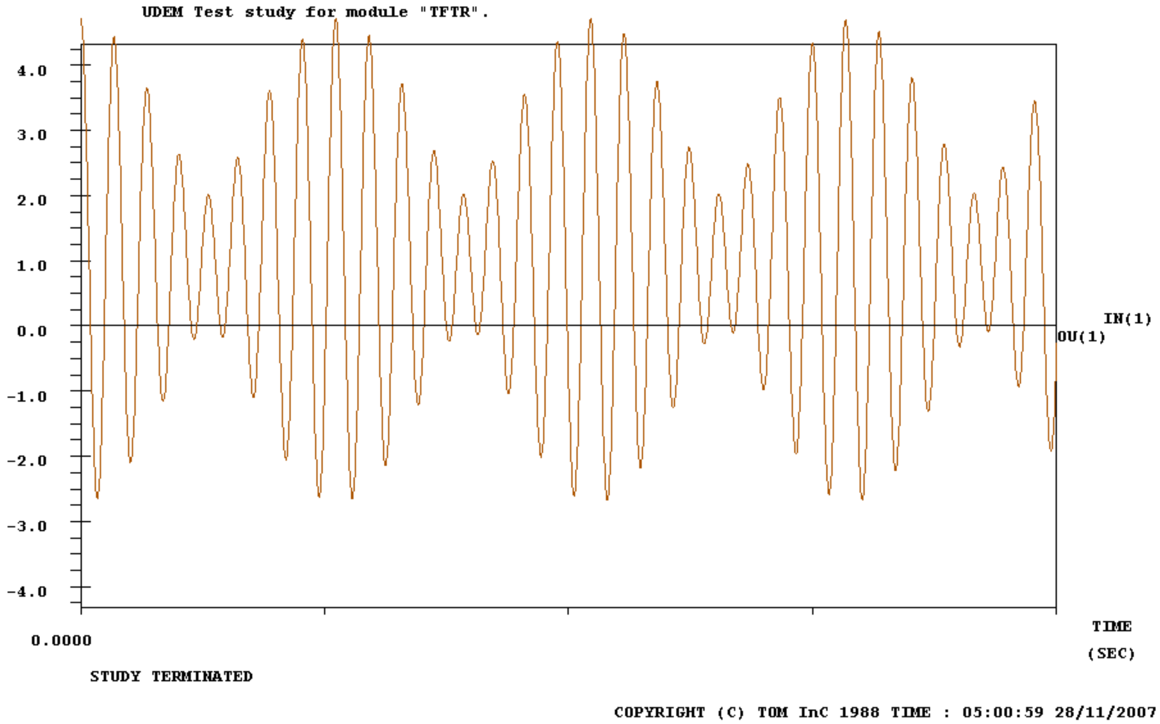


Figure V.3 Overvoltage in the generator side, time 0.002 sec



APPENDIX VI

ARCING GROUND PHENOMENA

The arcing ground has been the subject of much discussion from time to time. Figure AVI. 1 shows the sequence of events which occurs when an earth fault on insulated neutral system is not well established. In this case a fault to earth causes so little current to flow that the arc is extinguished and the system is restored to healthy condition. This was however the condition which leads to the fault, which then re-appears. As the phase rotates the possibility exists that current flow will cease at a natural zero, which in an inductive system occurs at a voltage maximum. Charge is trapped on the system and all three phases gradually move away from the balanced condition cantered about zero voltage until another fault occurs (for more information about this phenomenon, please refer to the note attached which is written in Farsi).

In high resistance earthling a high value resistor is chosen, as high as possible whilst retaining the ability to prevent arcing grounds. The arcing ground builds up at its most rapid steps every half cycle and the provision of earthing resistor gives a path for the discharge of the trapped charge. If the time constant of the RC combination is held to a value of one radian is 1/314.1516 sec, the over voltages will effectively be prevented from building up. To achieve this 3R in the zero phase sequence must, when multiplied by C, give a value of 1/314.1516. Hence R = Xc / 3 where XC = 1/314.1516*C. The resistor thus equals in ohmic value the total capacitance of all three phases to earth. The value is likely to be some thousands of ohms and such a resistor is difficult to make in reliable form, and hence, a single phase transformer is used to step up the current and reduce the voltage so that the resistor becomes much more robust. Most large generators including our generator are earthed by this system.

According to ELIN document 3-539 304, the following capacitance are recognized for the system:

Generator Cgen = 0.97 uF/phase
Transformer:
CTr HV-LV = 2.6 nF
Ctr HV-Gnd = 1.3 nF
CTr LV-Gnd = 11 nF

IPB: CIPB-Gnd = 6.9 nF (0.063 nF/m/phase, 110m)
Generator CB: 130 nF Generator side
260 nF Transformer side

St. Serv. Transf: Capacitance value not known (ABB supply)!

Total three phase capacitance 4.13 uF

Therefore, the capacitor Xc is 1/4.13*10**-6*314.1516 =770.75 Ohm

The resistor is selected to be 0.59 Ohm in the secondary side of a single phase transformer with the following characteristic:

16KVA, 9.09 / 0.24KV

Therefore, if we view the resistor from primary side the magnitude is 0.59*9.09**2 / 0.24**2 = 846.36 Ohm

The value does not match the requirements for the grounding resistor; however, the value of 0.54 Ohm (having not known the St. Serv. Tranf. Capacitance) was a better choice. Do not treat this value as a recommendation; it is not the intention of this report to recommend any value.

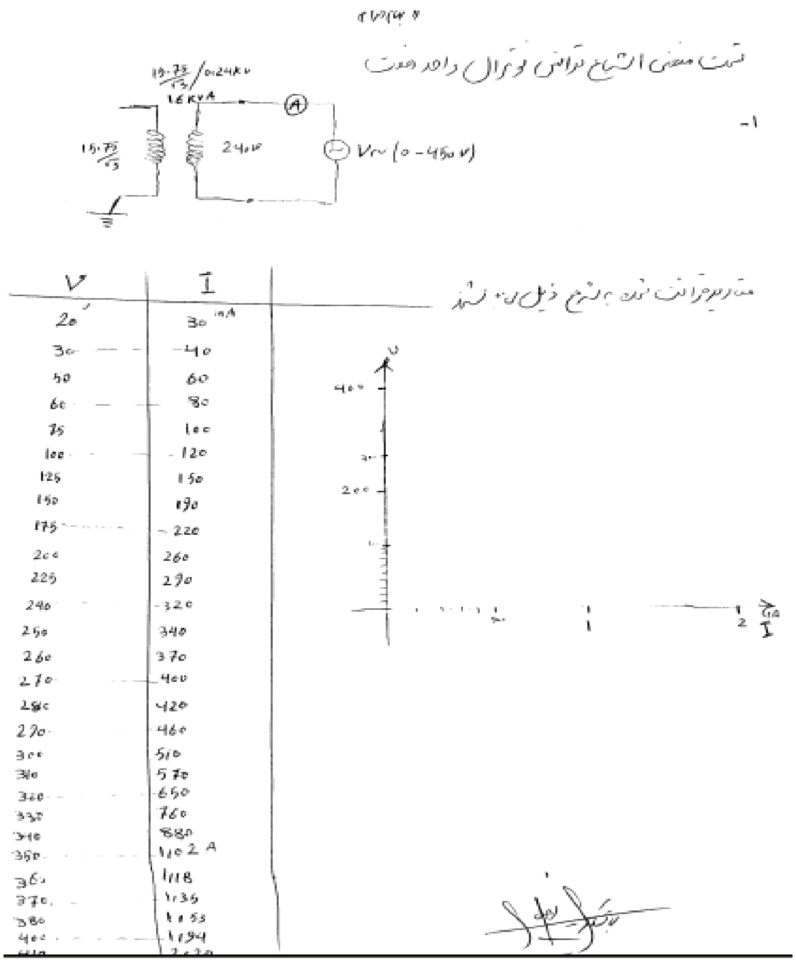
According to the mentioned ELIN document, this produce 100% voltage displacement in an earth fault condition.

AVI. 1 TESTING THE EARTHING TRANSFORMER

A test has been conducted on the earthing transformer to find out its saturation characteristics. Figure AVI.2 shows the result of the test. The results are summarized in table AVI. 1.

In a single phase fault condition the neutral voltage will give rise to 1.01 P.U. (to the voltage of the system prior to the fault) this is more than 240V. The result shows that there is no significant saturation in this situation. However, when considering the ferroresonance of PT described in the next appendix which will also produce overvoltages, and bearing in mind that the earthing transformer can also contribute to a ferroresonace effect, it is obvious that the selected transformer cannot properly handle its job and prevent the arcing ground phenomenon.

Figure AVI.2.Testing the earthing transformer:



۸۴/۲/۲۷

۱- تست منحنی اشباع ترانس نوترال واحد هفت

مقادیر قرائت شده به شرح ذیل می باشد

V	I
20	30 mA
30	40
50	60
60	80
75	100
100	120
125	150
150	190
175	220
200	260
225	290
240	320
250	340
260	370
270	400
280	420
290	460
300	510
310	570
320	650
330	760
340	880
350	1,02 A
360	1,118
370	1,135
380	1,153
400	1,194

Table AVI.1. Test results

Voltage applied to the secondary side (V)	Current (A)	Calculated magnetizing reactance (Ohm)	Voltage applied to the secondary side (V)	Current (A)	Calculated magnetizing reactance (Ohm)		
20	0.03	666.67	350	1.02	343.14		
30	0.04	750.00	360	1.18	305.08		
50	0.06	833.33	370	1.35	274.07		
60	0.08	750.00	380	1.53	248.37		
75	0.1	750.00	400	1.94	206.19		
100	0.12	833.33	410	2.2	186.36		
125	0.15	833.33					
150	0.19	789.47					
175	0.22	795.45					
200	0.26	769.23					
225	0.29	775.86					
240	0.32	750.00					
250	0.34	735.29					
260	0.37	702.70					
270	0.4	675.00					
280	0.42	666.67					
290	0.46	630.43					
300	0.51	588.24					
310	0.57	543.86					
320	0.65	492.31					
330	0.76	434.21					
340	0.88	386.36					

APPENDIX VII

FERRO RESONANCE EFFECTS

The application of grounded Y potential transformers on ungrounded systems with a Y or/and broken delta connection can be responsible for damaging over voltages as a result of resonant or ferroresonant action since the magnetizing reactance of the potential transformers becomes connected from phase conductor to ground. A complete description of this phenomenon need not be taken up here as it has been adequately treated in the literatures [2],[3],[4].

The ferroresonance would not be occurred if the electric system neutral is effectively grounded. Freedom from this particular type of phenomenon can be obtained even with ungrounded neutral operation by following the IEEE recommendations:

1- Select PT with line-to-line rated voltage. In our case the PT must be 15.75*1.73205KV in the primary side.
2- Apply a secondary loading resistor with a resistance not greater than 40 percent of the transformer magnetizing reactance. Please refer to the following test results to find out our plant situations.

As stated we are not going to provide a full scale simulation of this phenomenon in this report. The obvious consequences of the PT resonance in the system, is the amount of zero sequence current feeding to the single phase fault in the generator. From the results obtained in Appendix II (table II.2), it can be recognized that an oscillatory zero sequence current of magnitude 27-202A has been injected toward single phase fault point as the result of the occurrence of this phenomena. Note that the 3I0 reading numerical errors is 0.003*12500=37.5A.

Figure 2 shows the records of the system variables. The PT3-RS record is indeed the voltage of the phase T respect to phase S measured in the secondary of the potential transformer. There are two confusing measurement in respect to the waveform:

1- It does not show the system potential after GCB opening. This was found to be due to the opening of the secondary miniature fuses as the result of resonance. Test conducted shows the resonance noise heard from the transformer and the opening of this miniature fuse when the voltage applied to the secondary was more than 60V (110/1.73205) has happened in the test. Relay 64GB has gone in off position at time 183 msec, (so it sees the PT3 resonance until this time and considering the existence of low voltage Vts after this time) it suggest that the corresponding miniature has been opened at this time.
2- Before occurrence of the two phases fault, it has an angle division in respect to the voltage of phase T to S (the -180 degree shifted can be read from PT1 on the voltage ST, obtained from the zero crossing points 7.2 degree (0.4 msec 0.4*360/20)). This is the result of the reduction of the magnetizing reactance of the transformer which provides a parallel inductive path for the burden, so the phase shift will occur, and proves an overvoltage was presented which is due to a single phase fault in the system. The visual inspections show that a loose connection to the ground is presented in this secondary side too, but it had no effect in the above, it might be occurred because of the above resonance.
The results of handmade test and the loose connection location is indicated in the following figure (figure AVII.1), which also shows the probable faults that might exist inside the PT3. Table AVII.1 shows the result of the test

Table AVII.1. The result of test on secondary sides of PT shown below in two occasions

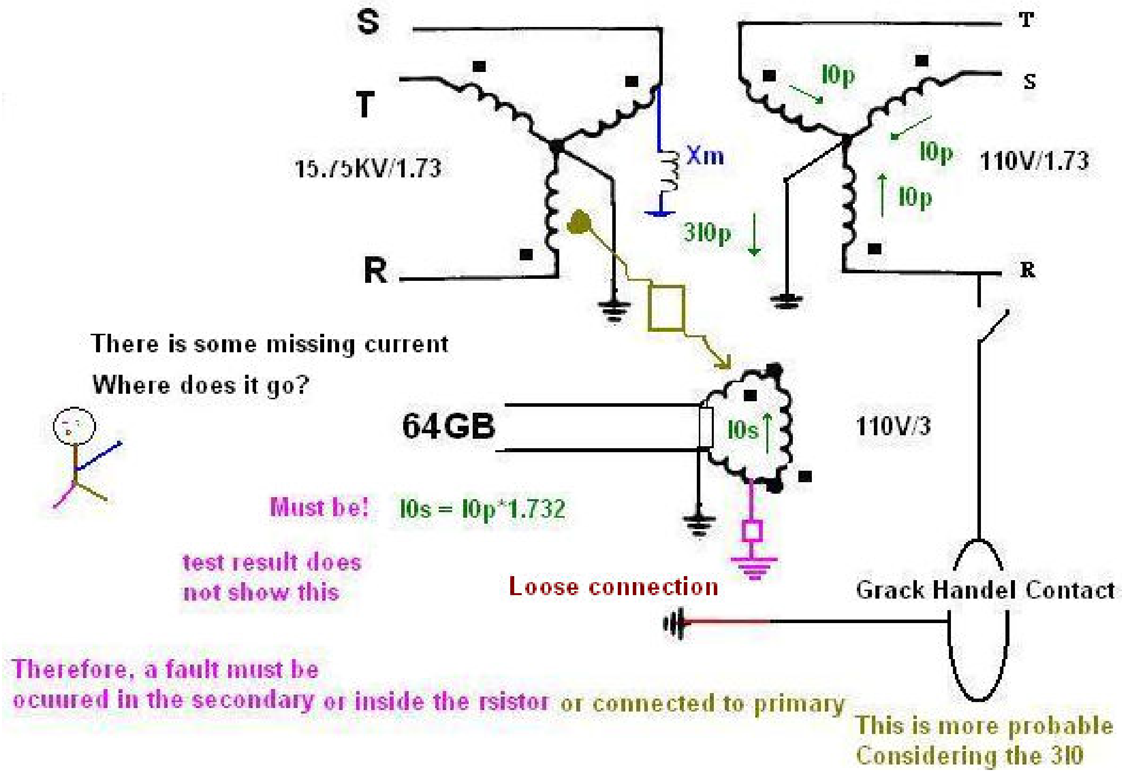
Voltage applied to the star connected secondary V0 (V)	Current of the injected voltage in the star connected secondary (A)	Voltage of open delta connected secondary across resistor (V)	Current of open delta secondary (A)				
10.	0.5	17.73	0.3				
20.2	0.7	34.8	0.41				
30.1	1.1	52.9	0.62				
40.2	1.5	69.9	0.71				
50.02	1.9	87.7	0.93				
60.04	2.4	104	1.2				

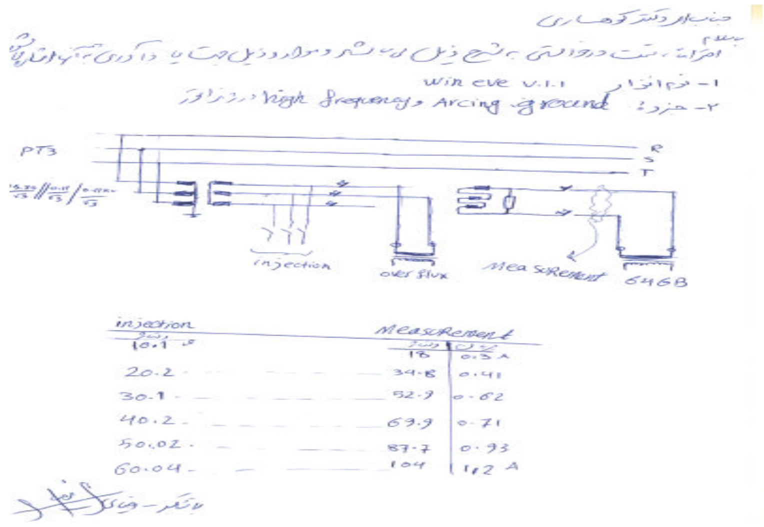
Voltage applied to the star connected secondary V0 (V)	Current of the injected voltage in the star connected secondary (A)	Voltage of open delta connected secondary across resistor (V)	Current of open delta secondary (A)				
10	0.5	17.73	0.3				
20	0.8	34.4	0.4				
40	1.5	69.4	0.7				
50	1.8	86.4	0.9				
60	2.7	106.5	1.3				
62	4.5	115.7	2.4				
64	7	120	3.3				

The magnitude of R from secondary side is approximately = 48-90 Ohm during the test or 90*100/0.11*0.11=743,801 P.U. in 100MVA base.

The magnitude of Xm is about 86 Ohm from secondary side point of view = 700000P.U. But when as a result of fault in the secondary side the zero flux of the secondary must flow to the air, the Xm0 will be reduced to a small value. The value can be calculated if the PT core dimensions are considered. However, the zero current flow of appendix II shows that this is about 40 P.U. on 100MVA bases. During this flowing of the zero current the primary side voltages increased and produced a ferroresonance effect.

Figure AVII.1 PT3 connection and test results, primary test





جناب آقای دکتر کوهساری

باسلام

اجرای تست در حالتی به شرح ذیل انجام شد و موارد ذیل جهت یادآوری به استحضار میرساند

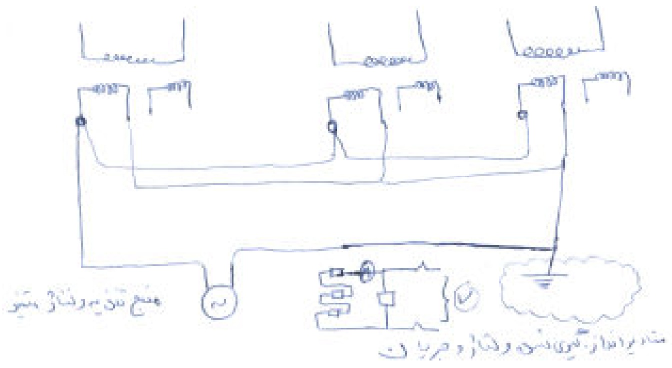
۱- نرم افزار win eve v.1.1

۲- حذف : ground Arcing و high frequency در رله

injection	Measurement	
ولتاژ	ولتاژ	جریان
10.1 v	18	0.3 A
20.2	34.8	0.41
30.1	52.9	0.62
40.2	69.9	0.71
50.02	87.7	0.93
60.04	104	1.2 A

با تشکر - [illegible]

مدار مربوط به تست PT3 :



نکته: در ترمینال مربوط به وایر زمین (ترمینال شماره 19) وایر زمین
بودن زمین کامل نبوده است loss conection

مدار اصلی اتصال PT3 در تابلو

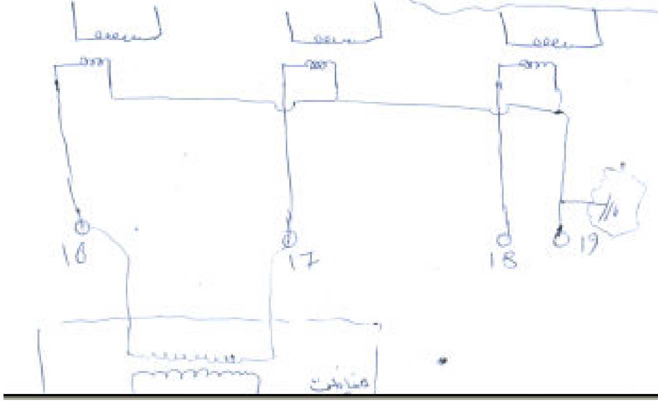
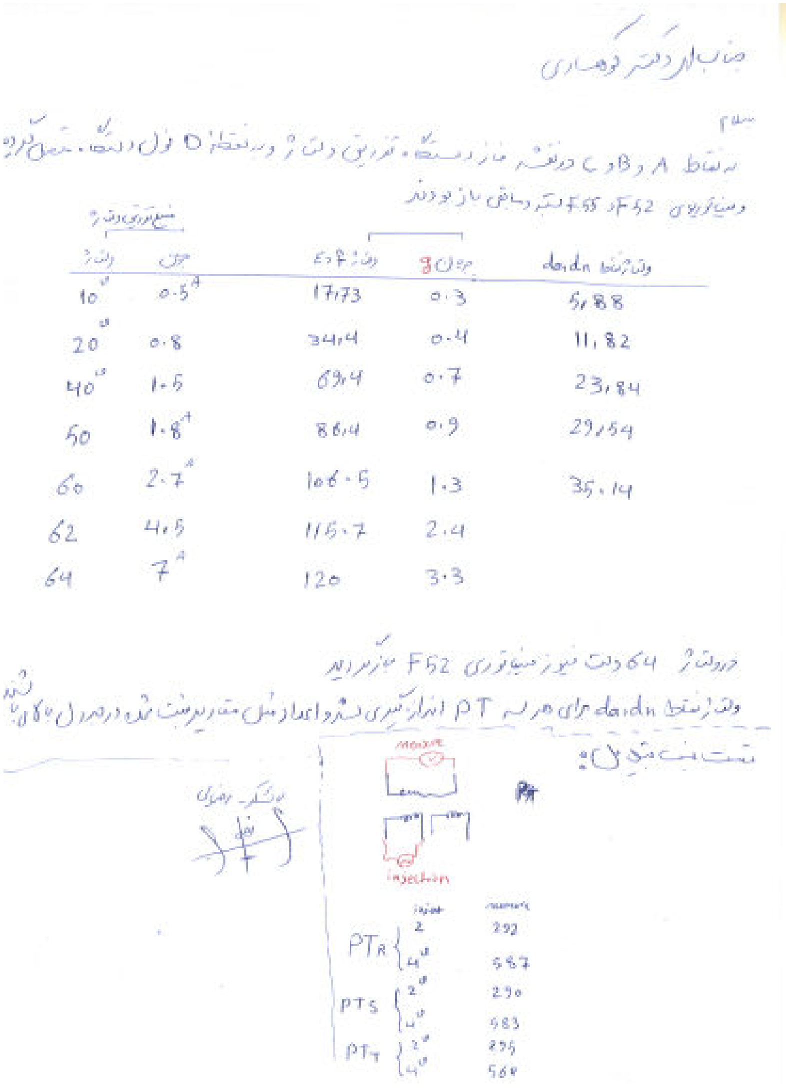


Figure AVII.2 PT3 connection and test results, tested again



جناب آقای دکتر [illegible]

سلام

به نقاط A و B و C در نقشه فاز دستگاه تزریق ولتاژ و به نقطه O نول دستگاه متصل گردید
و فیوزهای F52 و F55 دقیقاً باز بودند

منبع تزریق ولتاژ				
ولتاژ	جریان	ولتاژ E-F	جریان g	ولتاژ نقطه da,dn
10	0.5	17,73	0.3	5,88
20	0.8	34,4	0.4	11,82
40	1.5	69,4	0.7	23,84
50	1.8	86,4	0.9	29,54
60	2.7	106.5	1.3	35,14
62	4.5	115.7	2.4	
64	7	120	3.3	

در ولتاژ 64 ولت فیوز مینیاتوری F52 پرید

ولتاژ نقطه da,dn برای هر سه PT اندازه‌گیری شد و اعداد مثل مقادیر ثبت شده در جدول بالا [illegible] ثبت نشد:

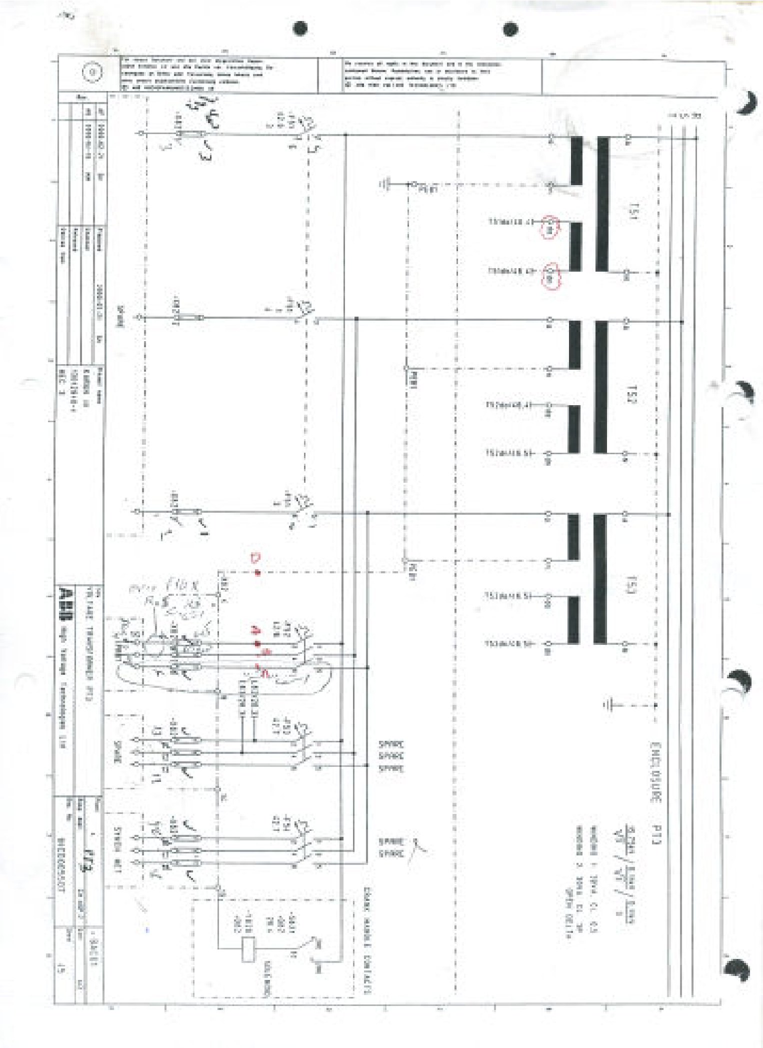
با تشکر - [illegible]

MEASURE

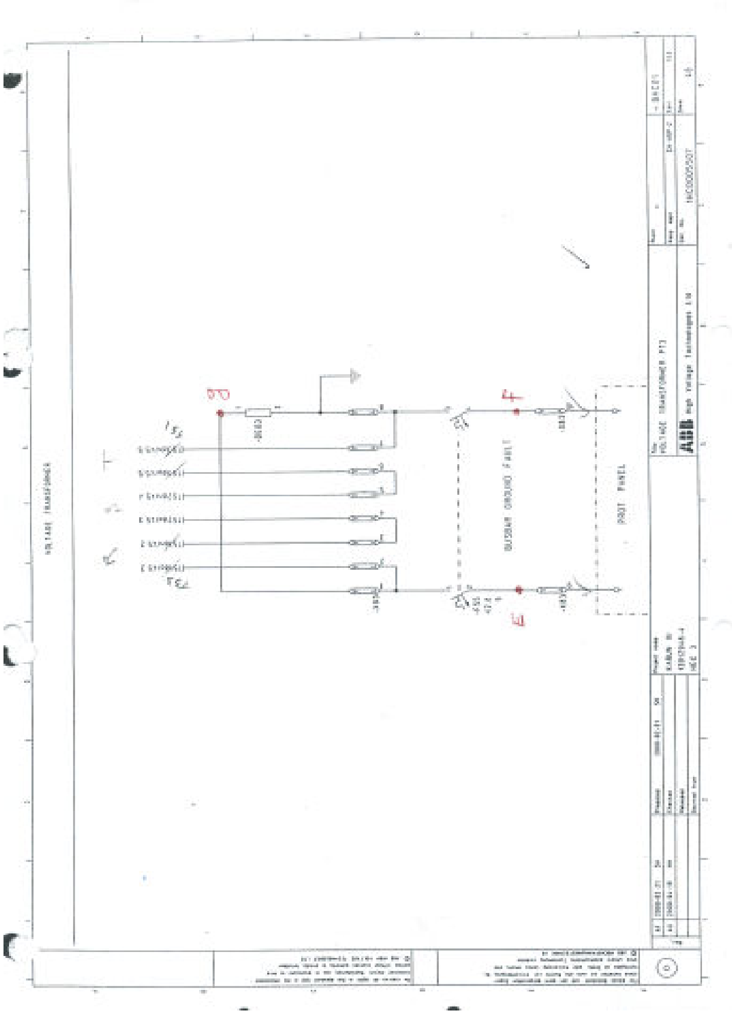
PT

injection

	input	measure
PTR	2	292
	4	587
PTS	2	290
	4	583
PTT	2	295
	4	564



TS1
TS2
TS3
SPARE
ENCLOSURE
PT3
ABB


VOLTAGE TRANSFORMER
BUSBAR GROUND FAULT
PROT PANEL
D
E
F
T51
T53
VOLTAGE TRANSFORMER PT3
ABB High Voltage Technologies Ltd
1HC0005507

APPENDIX VIII

GENERATOR WINDING CONNECTION

The stator winding is 4 times parallel connected and designed as wave winding. Therefore 4 connection groups, symmetrically distributed on the circumference, exist in NDE. Each of them has one line end and one neutral end per phase and parallel path (Elins report).

Figure AVIII.1 shows a schematic of the winding diagram. Table AVIII.1 shows the same in a tabular form. According to Elins report the damages caused by flash overs are presented on 3 of these 4 connection groups. However, when we follow up the slots, we have found that the damages addressed in the mentioned report are just existed in two connection groups as shown in Figure AVIII.2. This is completely in agreement with the sequence of the events described in section 5.

The other drawback of the Elins report is its emphasis on the melting or replacement of the materials. During the first 70-80 msec, that the GCB opens the fault, there is no time for the replacement of the materials or melting of these materials. All these melting and replacements would take place after this time, as the generator was rotating for about 15 seconds and the internal fault was fed through self excitation of the generator.

In appendix III, we proved that during the first 70msec, the only two phases fault occurred inside the generator windings was the one between slot 326 and 327. The damage in these slots was too low because of the small time that this two phases fault was being in the generator. After GCB opening, the first two phases fault had been extinguished, since other stronger faults are produced in the same windings. The opening overvoltages are responsible for producing the other faults as mentioned in section 5 and described in appendix V.

Figure AVIII.1 generator winding diagram

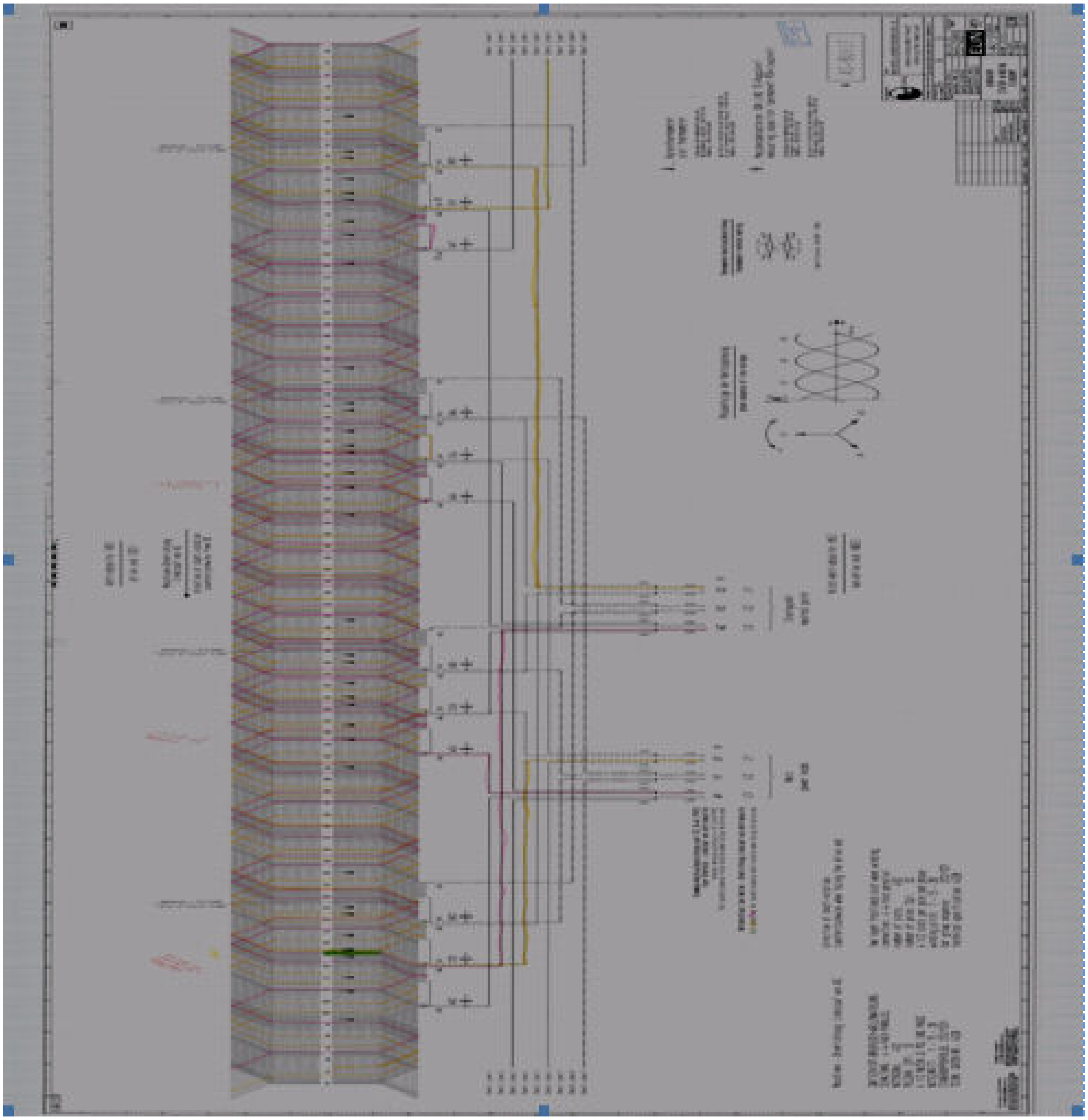


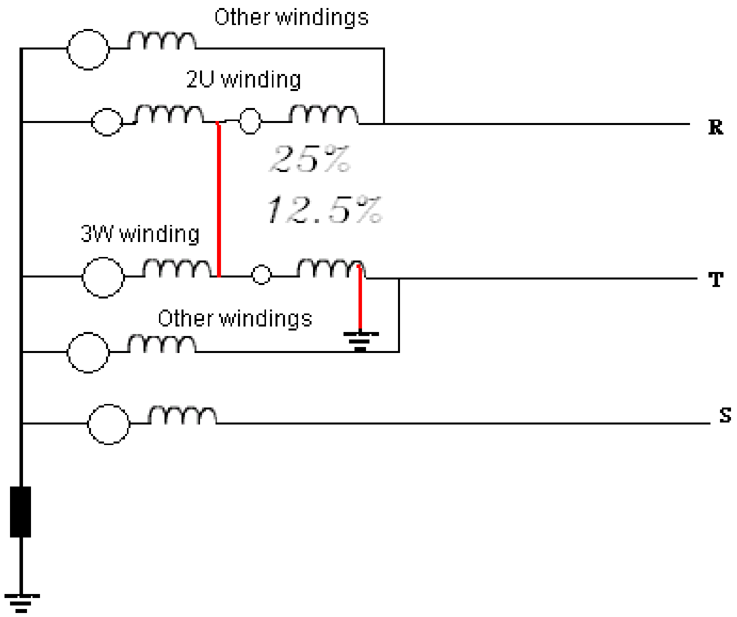
Table AVIII.1 Generator winding table: Single phase fault, Line to Line fault

Slot No.	Phase T								Phase S								Phase R							
	1W		2W		3W		4W		1V		2V		3V		4V		1U		2U		3U		4U	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
217					1	33																		
218			9					41																
219		49															18							
220				57															26					
221						65															34			
222																				8			42	
223																	50	16						
224										19									58					
225												27									66			
226											7			35										
227									15							43								
228			24							51														
229					32							59												
230							40							67										
231	48					2																		
232			56	10																				
233					64													17						
234							72													25				
235																					1	33		
236																			9					41
237									18									49						
238											26									57				
239													34									65		
240												8			42									
241									50	16														
242				23							58													
243						31							66											
244					3			39																
245		47	11																					
246				55															24					
247						63															32			
248								71															40	
249																	48					2		
250																			56	10				
251										17											64			

252												25											72	
253													1	33										
254											9					41								
255			22							49														
256					30							57												
257							38							65										
258	46					4																		
259			54	12																				
260					62															23				
261							70															31		
262																					3			39
263																		47	11					
264											24									55				
265													32									63		
266															40									71
267									48					2										
268											56	10												
269				21									64											
270						29									72									
271					5			37																
272		45	13																					
273				53															22					
274						61															30			
275								69															38	
276																	46					4		
277																			54	12				
278												23									62			
279														31									70	
280													3			39								
281										47	11													
282			20									55												
283					28									63										
284							36									71								
285	44					6																		
286			52	14																				
287					60															21				
288							68															29		
289																					5			37
290																		45	13					
291											22									53				
292													30									61		
293															38									69
294									46					4										
295											54	12												

296				19									62											
297						27									70									
298					7			35																
299		43	15																					
300				51															20					
301						59															28			
302								67															36	
303																	44					6		
304																			52	14				
305												21									60			
306														29									68	
307													5			37								
308										45	13													
309			18									53												
310					26									61										
311							34									69								
312	42					8																		
313			50	16																				
314					58															19				
315							66															27		
316																					7			35
317																		43	15					
318											20									51				
319													28									59		
320															36									67
321									44					6										
322											52	14												
323				17									60											
324						25									68									
325							1	33																
326		41			9																			
327				49															18					
328						57															26			

Figure AVIII.2 Fault location of the phases R and T windings



APPENDIX VIIII

WEATHER CONDITION

The weather condition and the lightning strikes possibility are investigated as the followings:

Figure VIIII.1 shows the weather condition obtained from Xian Weather Organization in that particular date (in Persian).

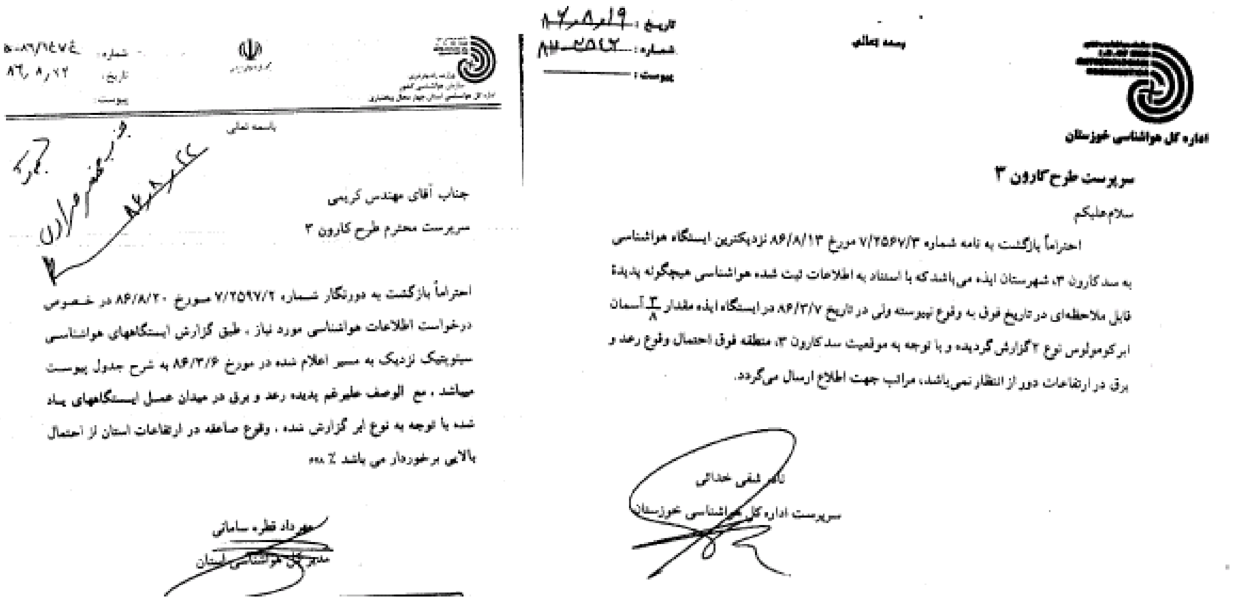
An investigation shows that the phase S of the X-Y 400KV line surge arrester counts a lightening discharge. The discharge had been happened between 16.1.86 till 12.6.86 (Persian dates)

The phase S of the generator no. 8 surge arrester counter shows three lightening discharges. The discharge had been happened between 15.2.86 till 15.4.86 (Persian dates)

Unit 7 arresters not recorded any discharges.

Considering the 300MVA 400KV/15.75KV YNd11 shown in Figure VIII.2, the phase S in 400KV is mutual coupled with RT winding in 15.75KV section. Phase S of the primary has a direct coupling with phase T of the secondary.

Figure VIIII.1 weather condition (written in Persian)



وزارت راه و ترابری
سازمان هواشناسی کشور
اداره کل هواشناسی استان چهار محال و بختیاری

شماره: ۵-۸۶/۱۶۴۷۴
تاریخ: ۸۶/۸/۲۲
پیوست:

باسمه تعالی

جناب آقای مهندس کریمی
سرپرست محترم طرح کارون ۳

احتراماً بازگشت به دورنگار شماره ۷/۲۵۹۷/۲ مورخ ۸۶/۸/۲۰ در خصوص درخواست اطلاعات هواشناسی مورد نیاز ، طبق گزارش ایستگاههای هواشناسی سینوپتیک نزدیک به مسیر اعلام شده در مورخ ۸۶/۳/۶ به شرح جدول پیوست میباشد ، مع الوصف علیرغم پدیده رعد و برق در میدان عمل ایستگاههای یاد شده با توجه به نوع ابر گزارش شده ، وقوع صاعقه در ارتفاعات استان از احتمال بالایی برخوردار می باشد ٪ ده

مهرداد قطره سامانی
مدیرکل هواشناسی استان

تاریخ: ۸۶/۸/۱۹
شماره: ۸۶-۲۵۱۲
پیوست:

بسمه تعالی

اداره کل هواشناسی خوزستان

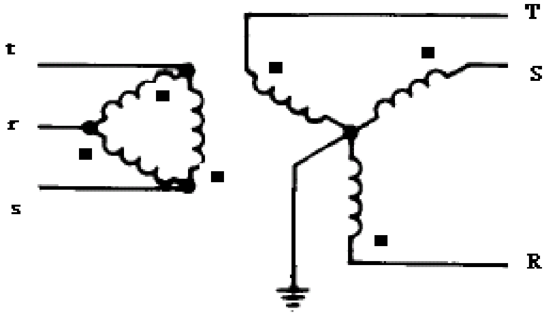
سرپرست طرح کارون ۳

سلام‌علیکم

احتراماً بازگشت به نامه شماره ۷/۲۵۶۷/۳ مورخ ۸۶/۸/۱۳ نزدیکترین ایستگاه هواشناسی به سد کارون ۳، شهرستان ایذه می‌باشد که با استناد به اطلاعات ثبت شده هواشناسی هیچگونه پدیدهٔ قابل ملاحظه‌ای در تاریخ فوق به وقوع نپیوسته ولی در تاریخ ۸۶/۳/۷ در ایستگاه ایذه مقدار ۲/۸ آسمان ابر کومولوس نوع ۲ گزارش گردیده و با توجه به موقعیت سد کارون ۳، منطقه فوق احتمال وقوع رعد و برق در ارتفاعات دور از انتظار نمی‌باشد، مراتب جهت اطلاع ارسال می‌گردد.

ناصر شفی خدائی
سرپرست اداره کل هواشناسی خوزستان

Figure VIIII.2 300MVA 400/15.75KV YNd11 TRANSFORMER CONNECTION ON UNIT 7 Coupling capacitor is 2.6 nF per phase.



APPENDIX X

PROTECTION RESPONSE

The protection equipments response during the events, are represented in table AX.1. The event lists shows the events occurred for the four relays, REGA, REGB, REL87, and RET87.

X.1 Fault flows

Having known that an internal LLG fault has occurred inside the generator, the followings are the magnitude of the fault flows of the above relays for this fault:

Relay REGA, and REGB:

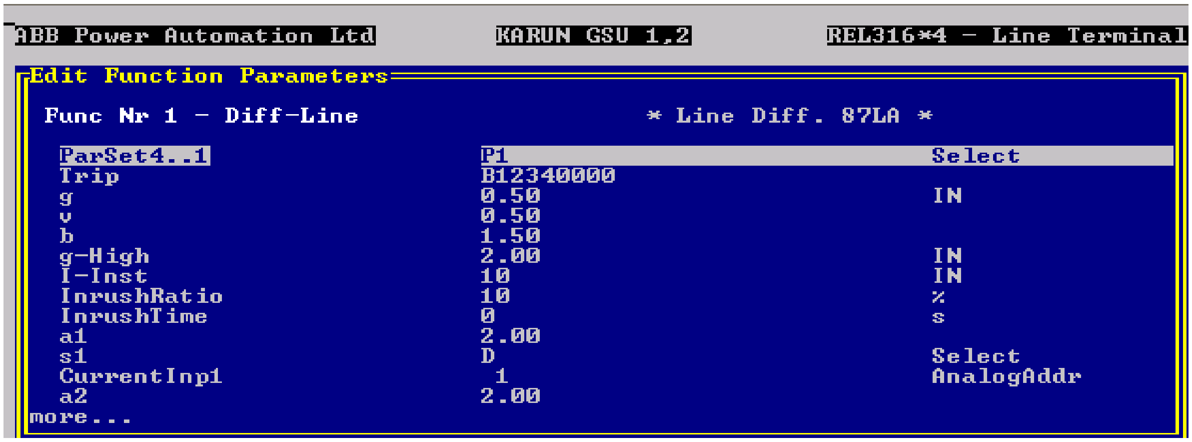
The fault currents and the differential magnitude of the faults are shown in appendix III which agrees with what is announcing by this relay.

Relay REL87:

The amount of current paths this relay according to the fault analysis is 2653 A. This is 2653*2/2000IN=2.653IN according to the relay differential settings. The stabilizing signals of this relay response for 1.5IN. Therefore, it sees the internal fault of generator and acts accordingly. The Definite time has also seen the events and acts accordingly. The relay gets off when the phase T has been opened by GCB.

The setting of this relay is shown in figure AX.1

Figure AX.1 settings of REL87



```
ABB Power Automation Ltd          KARUN GSU 1,2         REL316*4 - Line Terminal
Edit Function Parameters
  Func Nr 1 - Diff-Line                           * Line Diff. 87LA *

   ParSet4..1                  P1                             Select
   Trip                        B12340000
   g                           0.50                           IN
   v                           0.50
   b                           1.50
   g-High                      2.00                           IN
   I-Inst                      10                             IN
   InrushRatio                 10                             %
   InrushTime                  0                              s
   a1                          2.00
   s1                          D                              Select
   CurrentInp1                  1                             AnalogAddr
   a2                          2.00
 more...
```

```
ABB Power Automation Ltd          KARUN GSU 1,2         REL316*4 - Line Terminal
Edit Function Parameters
  Func Nr 2 - Current-DT                          *  *

   ParSet4..1                  P1                             Select
   Trip                        B12340000
   Delay                       01.00                          s
   I-Setting                   00.56                          IN
   MaxMin                      Max-Inrush                     Select
   NrOfPhases                  003
   CurrentInp                   1                             AnalogAddr
   BlockInp                    F                              BinaryAddr
   Trip                        S110 L10 ER                    SignalAddr
   Start                       ER                             SignalAddr
   RETURN/ENTER
```

```
ABB Power Automation Ltd          KARUN GSU 1,2         REL316*4 - Line Termina
Edit Function Parameters
  Func Nr 3 - Current-Inv                         *  *

   ParSet4..1                  P1                             Select
   Trip                        B12340000
   c-Setting                   2.00                           Select
   k1-Setting                  000.01                         s
   I-Start                     4.00                           IB
   t-min                       00.0                           s
   NrOfPhases                  3
   CurrentInp                   1                             AnalogAddr
   IB-Setting                  2.50                           IN
   BlockInp                    F                              BinaryAddr
   Trip                        S109 L09 ER                    SignalAddr
   Start                       ER                             SignalAddr
   RETURN/ENTER
```

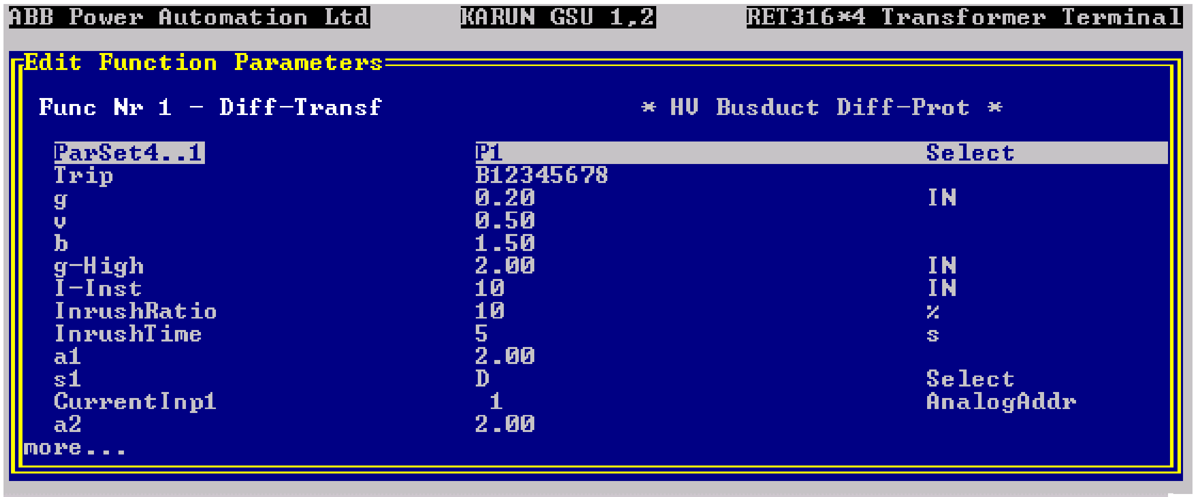
Relay RET316*4:

The amount of current paths this relay according to fault analysis is 2653 A in HV side, 2856 A for GSU1 and 439 A in GSU2. The stabilizing signal is SQRT (2856*(439+2653) = 2971A * 2/2000 = 2.97 IN. It produces 296 A differentials in phase S, 311 A in phase T and 293 A in phase R. The differential settings see these amount of current as 296*2/2000=0.3IN in phase S, 311*2/2000=0.3IN in phase T and 293*2/2000=0.3IN in phase R (the calculation are made using with PASHA protection system analysis not reported here). The relay settings are shown in figure AX.2. The stabilizing will prevent the differential to operate. The function of this relay during the fault is more or less as the response of REL316*4.

X.1 Event list sequences

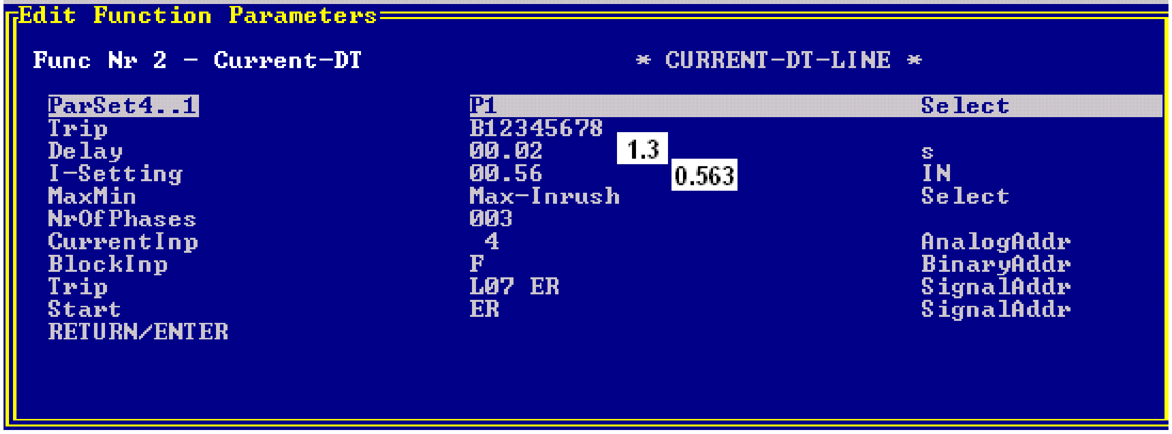
According to what are described in this document, the sequences of the protection system function according to the approximate time of the events are listed in table AX.1.

Figure AX.2 settings of RET87



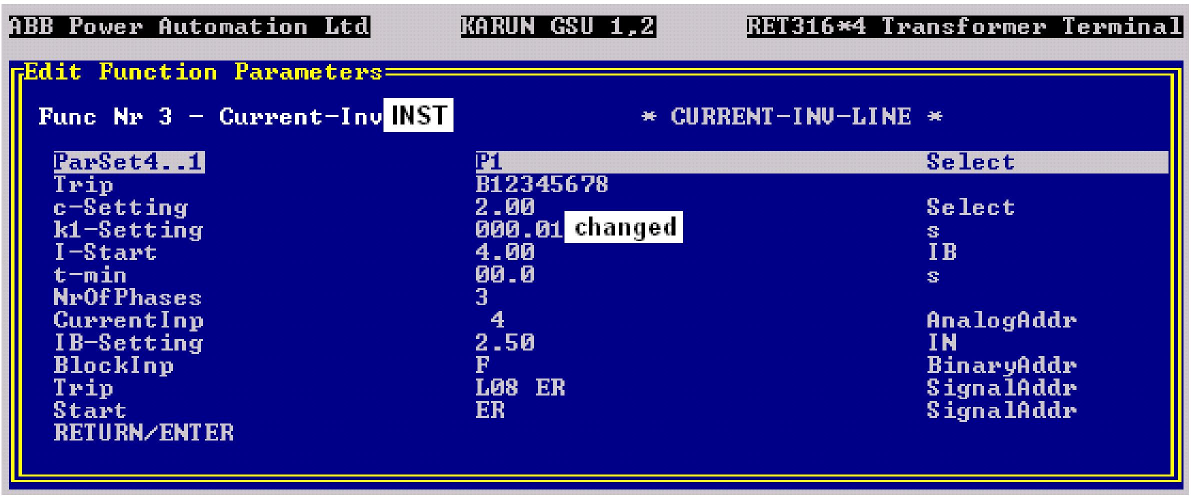
```
ABB Power Automation Ltd      KARUN GSU 1,2      RET316*4 Transformer Terminal
Edit Function Parameters
  Func Nr 1 - Diff-Transf                    * HV Busduct Diff-Prot *

    ParSet4..1            P1                          Select
    Trip                  B12345678
    g                     0.20                        IN
    v                     0.50
    b                     1.50
    g-High                2.00                        IN
    I-Inst                10                          IN
    InrushRatio           10                          %
    InrushTime            5                           s
    a1                    2.00
    s1                    D                           Select
    CurrentInp1            1                          AnalogAddr
    a2                    2.00
more...
```



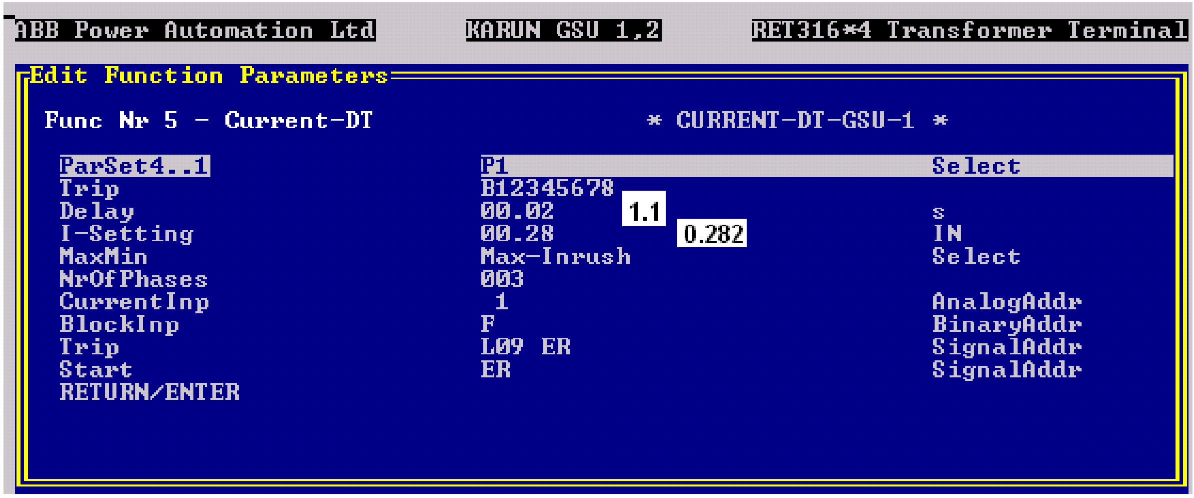
```
ABB Power Automation Ltd      KARUN GSU 1,2      RET316*4 Transformer Terminal
Edit Function Parameters
  Func Nr 2 - Current-DT                     * CURRENT-DT-LINE *

    ParSet4..1            P1                          Select
    Trip                  B12345678
    Delay                 00.02     1.3               s
    I-Setting             00.56       0.563           IN
    MaxMin                Max-Inrush                  Select
    NrOfPhases            003
    CurrentInp             4                          AnalogAddr
    BlockInp              F                           BinaryAddr
    Trip                  L07 ER                      SignalAddr
    Start                 ER                          SignalAddr
    RETURN/ENTER
```



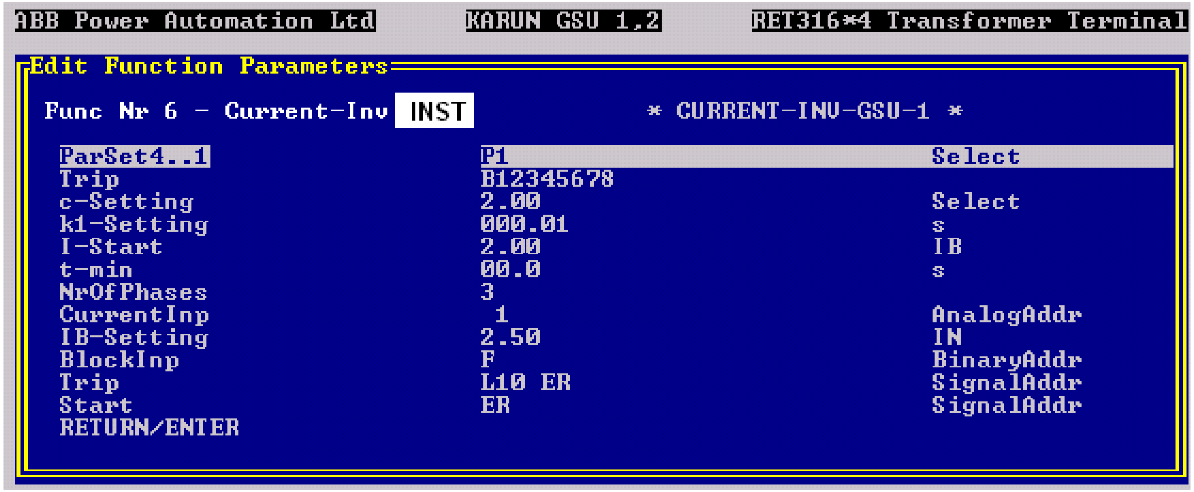
```
ABB Power Automation Ltd        KARUN GSU 1,2        RET316*4 Transformer Terminal
Edit Function Parameters
 Func Nr 3 - Current-Inv INST              * CURRENT-INV-LINE *

  ParSet4..1                  P1                            Select
  Trip                        B12345678
  c-Setting                   2.00                          Select
  k1-Setting                  000.01 changed                s
  I-Start                     4.00                          IB
  t-min                       00.0                          s
  NrOfPhases                  3
  CurrentInp                   4                            AnalogAddr
  IB-Setting                  2.50                          IN
  BlockInp                    F                             BinaryAddr
  Trip                        L08  ER                       SignalAddr
  Start                       ER                            SignalAddr
  RETURN/ENTER
```



```
ABB Power Automation Ltd        KARUN GSU 1,2        RET316*4 Transformer Terminal
Edit Function Parameters
 Func Nr 5 - Current-DT                    * CURRENT-DT-GSU-1 *

  ParSet4..1                  P1                            Select
  Trip                        B12345678
  Delay                       00.02  1.1                    s
  I-Setting                   00.28     0.282               IN
  MaxMin                      Max-Inrush                    Select
  NrOfPhases                  003
  CurrentInp                   1                            AnalogAddr
  BlockInp                    F                             BinaryAddr
  Trip                        L09  ER                       SignalAddr
  Start                       ER                            SignalAddr
  RETURN/ENTER
```



```
ABB Power Automation Ltd       KARUN GSU 1,2       RET316*4 Transformer Terminal
Edit Function Parameters
 Func Nr 6 - Current-Inv INST          * CURRENT-INV-GSU-1 *

  ParSet4..1                  P1                             Select
  Trip                        B12345678
  c-Setting                   2.00                           Select
  k1-Setting                  000.01                         s
  I-Start                     2.00                           IB
  t-min                       00.0                           s
  NrOfPhases                  3
  CurrentInp                   1                             AnalogAddr
  IB-Setting                  2.50                           IN
  BlockInp                    F                              BinaryAddr
  Trip                        L10 ER                         SignalAddr
  Start                       ER                             SignalAddr
  RETURN/ENTER
```

Table AX.1 Event lists

U7-RELGA				Time of event Announced Occurrence	
32193	04:43;07.436	GenStart	OFF		
32194	11:04;25.166	GenStart	ON		
32195	00:00;00.000	44 64GB Gen.Busbar E/F Start	ON	0	0
32196	00:00;00.003	GenTrip	ON		
32197	00:00;00.003	GenTripMem	ON		
32198	00:00;00.003	37 87G Gen. Differential Trip	ON	3	3
32199	00:00;00.006	32 Delay for 50BF Start	ON	6	3
32200	00:00;00.020	37 87G Gen. Differential		20	3
		10.54 IN (Id-R)			
32201	00:00;00.020	42 27 Gen. Undervoltage Start	ON	20	3
32202	00:00;00.023	37 87G Gen. Differential		23	3
		10.62 IN (Id-T)			
32203	00:00;00.036	Bin.Inp. Nr.14/11 (N/A-TCS)	ON	36	3
32204	00:00;00.043	37 87G Gen. Differential		43	3
		0.34 IN (Id-S)			
32205	00:00;00.070	24 40 Integrator Start	ON	70	56
32206	00:00;00.080	Bin.Inp. Nr.15/ 4 (Generator C.B. is open)	ON	80	65
32207	00:00;00.080	12 GCB/DS is open BinOutput	ON	80	65
32208	00:00;00.080	17 f11orf12orf13orf28 BinOutput	ON	80	65
32209	00:00;00.081	41 DisturbanceR BinOutput	ON	81	65
32210	00:00;00.100	42 27 Gen. Undervoltage Start	OFF	100	65
32211	00:00;00.133	Bin.Inp. Nr.14/ 2 (Excitation external tr)	ON	133	100
32212	00:00;00.136	2 Excitation ext. trip BinOutput	ON	136	100
U7-RELGB					
38014	11:07;31.711	GenStart	ON		
38015	00:00;00.000	GenStartMem	ON		
38016	00:00;00.000	30 49S Stator overload Start	ON	4	2
38017	00:00;00.003	40 64S(1)95%St.E/F-CBopen Start	ON	7	2
38018	00:00;00.006	45 50S Gen. Interturn Start	ON	10	3
38019	00:00;00.016	26 21G(1)Zmin.(GCBclosed) Start	ON	20	3
38020	00:00;00.016	27 21G(2)Zmin/CBcl.+open Start	ON	20	3

38021	00:00;00.016	29 46.2 Start	ON	20	3
38022	00:00;00.023	36 51ET Excit.Tr.O/C Inv. Start	ON	27	3
38023	00:00;00.026	38 51V(1) (Gen.CB closed) Start	ON	30	3
38024	00:00;00.026	39 51V(2) GenCB Cl.oropen Start	ON	30	3
38025	00:00;00.033	Bin.Inp. Nr.14/11 (N/A-TCS)	ON	36	33
38026	00:00;00.076	Bin.Inp. Nr.15/ 4 (Generator C.B. is open)	ON	80	65
38027	00:00;00.076	12 GCB/DS is open BinOutput	ON	80	65
38028	00:00;00.076	18 f12 or f13 BinOutput	ON	80	65
38029	00:00;00.076	19 f12 or f17 BinOutput	ON	80	65
38030	00:00;00.076	20 f11orf12orf46 BinOutput	ON	80	65
38031	00:00;00.080	26 21G(1)Zmin.(GCBclosed) Start	OFF	84	69
38032	00:00;00.090	38 51V(1) (Gen.CB closed) Start	OFF	94	79
38033	00:00;00.130	Bin.Inp. Nr.14/ 2 (Excitation external tr)	ON	134	100
38034	00:00;00.130	GenTrip	ON		
38035	00:00;00.130	GenTripMem	ON		
38036	00:00;00.130	2 Excitation ext. trip BinOutput	ON	134	100
38037	00:00;00.130	31 Delay for 50BF Start	ON	134	100
REL					
6192	15:31;31.206	1 Line Diff. 87LA Stabilizing	ON	10	3
6193	15:31;31.213	GenStart	ON		
6194	00:00;00.000	2 Current-DT Start	ON	17	3
6195	00:00;00.040	1 Line Diff. 87LA Stabilizing	OFF	71	67
6196	00:00;00.041	2 Current-DT Start	OFF	72	67
RET					
13471	15:29;16.535	1 HV Busduct Diff-Prot Stabilizing	ON	due to calc.22	3
13472	15:29;16.535	GenStart	ON		
13473	00:00;00.000	5 CURRENT-DT-GSU-1 Start	ON	gen8 22	3
13474	00:00;00.010	2 CURRENT-DT-LINE Start	ON	32	3
13475	00:00;00.045	2 CURRENT-DT-LINE Start	OFF	67	67
13476	00:00;00.050	5 CURRENT-DT-GSU-1 Start	OFF	72	67
13477	15:29;16.585	GenStart			

			OFF		
13478	15:29;16.588	1 HV Busduct Diff-Prot Stabilizing	OFF	75	67

References:

[1] Allan Greenwood, "Electrical Transients in Power systems", John Wiley & Sons, Inc. Press

[2] Donald Beeman, "Industrial Power System Handbook", McGraw-Hill Book Company press

[3] Shott, H.S., and H. Peterson, "Criteria for Neutral Stability of Wye-Grounded Primary Broken Delta Secondary Transformer Circuits", AIEE Transactions on Power Systems, vol. 60, Nov. 1941

[4] D.A.N. Jacobson, R.W. Menzies, "Investigation of Station Service Transformer Ferroresonance in Manitoba Hydro’s 230-KV Doresey Convertor Station", IPST,2001 – International Conference on Power Systems Transients, Rio de Janeiro, June 24-28, 2001

[5] Foad & Anderson, "Power System Dynamics", John Wiley & Sons, Inc. Press