Thyristor power supply filtering for a 0.5 MW heat-transfer-loop

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Thyristor Power Supply Filtering for
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by

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Abstract

Problems connected with operation, loading and protection of a 0.5 MW, 5000 Amp. inductively filtered, thyristor power-supply for a heat-transfer experimental-loop, are discussed. This is partly based on a new, general computer program for thyristor power-supplies.

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Contents

Introduction

In the Section of Experimental Heat-Transfer (SEHT), two 0.25 MW thyristor controlled DC-power supplies of the ASEA type YMVD exist with a parallel coupling possibility. Some problems during operation showed up, due to the superimposed AC-components. Two filter-inductances has been ordered. The present report is concerned with the filtering and coupling problems of thyristor powersupplies. A computer program simulating thyristor power-supplies has been made and results and conclusions are given.

Description of Loop, Power-supplies

The supplies are modified type YMVD giving 100 V, 2500 A each. The primary side of the main-transformers for the two supplies are differently coupled so that a 12-pulse coupling is possible by parallel coupling. A z-type primary is shown in figures 1 and 2.

The secondary consists of 6 windings in a double star-connection with single rectification in each winding by a thyristor. See fig. 3.

This connection will for a sufficient large inductance in the load always present a current path. Therefore no free-wheeling (or protecting diode) is necessary for the (steady) inductance current.

A thyristor power-supply behaves radically different when the load has an inductive component of a certain size, or not.

One key-point in the functioning of a thyristor is that when the conduction first have been started in the positive period by an outer signal, then the thyristor will continue to conduct until the current through it is very near zero. A sufficiently large load-inductance will continue to drive the current through the thyristor until another thyristor ignites and begin to carry the inductance- and load-current.

As mentioned above, the thyristor coupling in the present supplies does not need a free-wheeling-diode when the load has an inductive component. On the other hand there can be a dis-advantage by this, as the inductive current has to work against the induced voltage in the secondary transformer windings during a part of the time, so the smoothing properties of the inductance are reduced.

The free-wheeling diode only comes into play (conducts) when there is an inductance in the circuit and when the conducting periods of the single thyristors are not in contact or in other words, for quite low power levels of the supply. One property of having a free-wheeling diode in the circuit is that the polarity of the load-voltage is assured to be non-negative. Another property is that for low power levels a somewhat better filtering is achieved.

Calculation Method

A Fortran-code was made, which simulates the present thyristor-power-supplies and several other types for that sake. The main idea has been to specify on beforehand how the thyristor voltages behave. Then a Fourier-transform is executed on the voltages. The load and inductance in complex-representation is used to modify the Fourier spectrum, which finally is back-transformed to time functions, concerned with the load.

The modified Fourier spectrum will give frequency-distributions. The time functions will give effect factors and max. values.

Detailed running-instructions are included in the commented first part of the code. A few selected results are shown in this report.

The equivalent diagram shown in Fig. 6 or rather the similar for a single supply is what for the moment is coded in the program. It can with relative ease be supplemented with other filtering scemes, as long as those does not interfere with the predetermined ignition-sceme. It is also possible by this method to find the transfer function from test section-power to test-section surface-temperature, for example.

Inductances

The ordered iron-inductance is designed for 2500 A and has an inductance which varies with the current. (150 μH for 250 A, 34 μH for 2500 A). 4 windings are supplied with a possibility of reconnecting.

At an early stage an air inductance was considered. It would have a diameter of 0.5 m and a length of 0.5 m. 30 windings of 0.3 mm. Aluminum plate 0.5 m wide. The stray-fields would affect the surroundings in several meters neighbourhood.

The loop-leads and their path will have a stray-inductance of 5-10 μH depending of closeness of the conductors.

The present connection between loop and power-leads forms a 1 m by 10 m rectangle, the self-inductance of which is 5-10 μH.

Characteristic frequencies

It has been found very practical to use the characteristic frequency of the loop-inductance-resistance-combination. A nomogram for that purpose have been included as Fig. 8.

The cut-off frequency for the R-L-filter of a 300 Hz power-supply should be 100-150 Hz if 10 times reduction of the AC-voltage is wanted. The reason for this large effect layes in the high content of harmonic frequencies in the thyristor voltage.

Depending of the anticipated experiments, the R-L-cut-off frequency of course also can be too low, so that the power cannot follow prescribed functions, or so that a power-close-down at burn-out takes too long a time.

Physical Effects of pulsating Power

Apart from the effects from the magnetic field, temperature induced stresses in the heating elements exists, ref. 3.

Furthermore, if the channel conditions corresponds to sub-cooled boiling and the heating element is in direct contact with the fluid, the possibility of pulsating boiling exists. The frequency of this phenomena is 600 Hz for a single (300 Hz) power supply. A pulsating-boiling presumerably will increase the heat-transfer coefficient and the mixing.

The magnetic field in the test section

The problem will be considered from the point-of-view of a straight infinitely long circular conductor. The magnetic field forms circles around the conductor. The field strength, B (Wb/m^2) can be calculated from:

$$B = 2_{10}{-7} \cdot I/r$$

where I is the current in Ampere and r is the distance in meters from the center of the lead.

For $r = 0.02$ m, $I = 2000$ A:
$B = 0.02\ Wb/m^2 = 200$ Gauss

The induced voltage, E, in a rectangular coil of length l, meters, placed in the plane of the lead, from distance r_1, to distance r_2, meters, giving a width of $(r_2 - r_1)$ to the coil, is:

$$E = N \cdot l \cdot 2_{10}{-7} \cdot \ln(r_2/r_1) \cdot \frac{dI}{dt}$$

where N is the number of windings.

A single winding ($0.01 \cdot 0.01\ m^2$), placed in a plane containing the conductor, at a closest distance 0.01 m and with a dI/dt of $5_{10}5$,

$$E = 0.01 \cdot 2_{10}7 \cdot 0.69 \cdot 5_{10}5 = 0.69 \text{ mV}$$

The metal pressure-carrying-system which eventually would surround the conductor will have no effect in reducing induced voltages in outside coils.

A suitable choice of path for the return conductor can diminish outside fields.

<u>Overview</u>

1) The super-imposed alternating current (AC) which is a left-over from the rectification has for a single supply the frequency, 300 Hz (600 Hz for a matched double). The typical amplitude (load = 40 m Ohm) can reach 35 volt effective. Componentc of multipla of the above mentioned basic frequencies, the amplitudes of which will decrease approximately with the inverse frequency.

2) The inductance-filter to be used, will reduce the superimposed AC-voltage with a factor approximately of 10. The parameter of importance is the time constant, T, formed by the inductance (non-linear with the mean current for iron cores) and the total load resistance, R. (R from 0 to 0.130 Ohm).

$$T = (2\pi \cdot L)/R$$

This time constant must be at least somewhat larger than the time constant corresponding to the basic super-imposed AC voltage (300 Hz $\simeq$ 0.0033 secs). On the other hand, if the time constant is too large the test-loop cannot be used to investigate dynamic phenomenaes concerned with power, faster than approximately two times this time constant.

The range of load resistances that can be covered in the actual set-up for one power supply with well-filtered voltages is thus 0.130 Ohm to 0 Ohm, the lower limit being precisely determined by the <u>fastest</u> responsetime wanted. With respect to the ladder, the maximum value of the actual inductance must be used:

$$T_{max} = L_{max} \cdot 2\pi/R = 150_{10}6 \cdot 6.28/R \simeq 10^3/R \text{ sec}$$

For R = 0.01 Ohm, T_{max} = 0.1 sec.

For R = 0.04 Ohm, T_{max} = 0.025 sec.

3) The range of load resistances the actual supply can accomedate depends on the max. power wanted. The absolute maximum of power that is delivered is 250 KW for 2500 A and 100 V and R = 0.040 Ohm.

For R below 0.040 Ohm the supply is current-limited at 2500 A. For R = 0.01 Ohm the power is 31 KW at 12.25 V.

For R above 0.040 Ohm the supply is voltage limited at 100 V.

For R = 0.1 Ohm the power is 100 KW at 952 A.

Apart from this power limit,which is unescapable, the associated time constants can be adjusted by using an extra load resistance, coupled either in parallel or in series to the load. The price for this is the waste-heat produced in this resistance.

Another possibility for adjusting the time constants layes in reconnecting the inductance: If the response time is too long for f.ex. 0.005 Ohms/load, then half the no of windings (2) could be used giving only a quarter of the original inductance.

4) It is possible to connect a so-called free-wheeling diode over the output of the supply. For low-power-levels this will better the filtering with a factor app. 2-4. Furthermore now no negative voltages can exist over the load. This could be important with respect to the instrumentation that could be used.

Such a diode will cost app. 1000 D.Kr. and one for each supply is needed. It is not recommended as an immediate acquisition.

In Fig. 14-17 calculational results are shown.

5) Anormaleous occurrencies in the load, such as breaks in the connection, will, with an inductance in the circuit give rise to very high voltages (several kvolts) in the part of the load connected to the inductance. Instrumentation , test-section and inductance may well be

damaged. As the highest voltage over the load normally is around 120 volts (over the inductance it is less) an overvoltage-protection should exist, and should activate at a voltage of 170-200 Volts. The time of reaction should be around 0.1 ms as can be calculated by considering the defining equation for an inductance to get a characteristic time for an incident:

$$-e = L \cdot \frac{di}{dt}$$

or

$$200 = 150_{10}6 \cdot 2500/dt$$

$$dt = 1.8 \text{ msec.}$$

The energy stored in the inductance is

$$\frac{1}{2} L \cdot i^2 = \frac{1}{2}\, 100_{10}6 \cdot 2000^2 \simeq 200 \text{ Joule}$$

For a parallel coupled supply set-up 400 Joule is relevant.

If an incident occurs the power supply instant-interrupt circuit must be activated, besides that the here proposed overvoltage circuit is activated.

The overvoltage protection circuit can either be placed across the load or over the inductance.

The simpiest and most permanent solution is to place the protection circuit over each inductance, permanently connected. The leads to the loop also have an inductance $\simeq$ 5-10 μ Henry. As a secondary protection a protection circuit may well have to be placed immediately across the test section.

6) Two power supplies can be parallelly coupled. There can be load-distribution problems and the full extent of these is not known. The coupling should be so that the two inductances is placed in front of each supply and the parallel coupling is made after the inductances. If this does not work satisfactory a special current-distribution-transformer may have to be installed in the parallel-connection point.

7) Two power supplies can be matched (so that their phases differ by 1/12 of a cycle) and according to the manufacturer this is the case with the present ones. If a perfect load-shaping occurs the left-over super-imposed alternating current will have a minimum frequency of 600 Hz as opposed to 300 Hz.

A frequency selective voltmeter at 300 Hz could eventually become a good instrument for the operation of the loop. The accuracy should be low. The range of sensitivity should go from 50 volts to 0.1 volt-eff. The balancing of the two power supplies is then accomplished by nulling this indicator.

An even simpler monitoring device would consist of a 10 cm diameter coil placed in the circular magnetic field of the power leads with the output fead directly into a common loudspeaker. The no of windings would have to be determined by experiments, eventually a stepping-up transformer could be used.

8) Disturbances to the mains.

The operation of the thyristor power supplies may affect the power-grid. The 3-phase disturbing frequencies will then be 300 Hz $\pm$ 50 Hz or 250 Hz and 350 Hz, or for a matched set of power supplies 550 Hz and 650 Hz.

For further information see ref. 5.

Conclusion

The envisaged filtered loop power supply will for planned load- and inductance matching have small residual alternating current (AC) voltage 2-5 volts in the supply voltage (300 Hz).

A dummy load of approximately 10-20 m Ohms can be necessary.

At least two overvoltage protection devices (200 Joule, each) are necessary, see fig. 6.

Three limiting factors are present:

1) Power matching of load resistance.

2) Filtering efficiency.

3) Response time for transient operation.

<u>References</u>

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2. Gentry, Gutzwiller, Holonyak, Von Zastrow. Semiconductor Controlled Rectifiers: Principles and Applications of p-n-p-n devices. Prentice-Hall 1964.

3. Krebs, L., Malang, S., Politzky, H.M. and K. Rust. Vor- und Nachteile von Thyristoranlagen zur Stromversorgung elektrisch beheitzer Stäbe hoher Leistungsdichte. KFK 1835. (Oct. 73). Kernforschungszentrum Karlsruhe.

4. M.O. Jørgensen. Almindelig Elektroteknik I-IV. Akademisk Forlag, Kbhvn. 1962.

5. Sven Ivner. Nätåterverkan från Strömriktera. ASEA Tidning 1970 <u>6</u> pp 133-136.

Print-out of Commented Program-Head.

```
FILE  6         (KIND=PRINTER,TITLE='SEHTLOOP')
FILE  5         (KIND=DISK,TITLE='LOOPDATA',FILETYPE=7)
C     ====================================================================
C     ====================================================================
C
C
C         T H Y R I S T O R - P O W E R - S U P P L I E S.
C
C                          F. W. CORTZEN
C                 SECTION FOR THERMOHYDRAULICS
C                         DANISH A. E. C.
C
C
C
C
C     INPUT PARAMETERS.
C     ================
C
C     ALL INPUT PARAMETERS COME THROUGH ONE NAMELIST, INL,
C     WHICH STARTS WITH A  &INL  IN COLUMN 2,
C     AND WHICH ENDS WITH   &END
C     IN BETWEEN THESE  COMMANDS THE PARAMETERS ARE GIVEN VALUES,
C     BY NAME, E.G.    IADM=0, RPASE=10000.
C     THOSE PARAMETERS NOT GIVEN NAME BY THIS NAMELIST
C     HAVE DEFAULT VALUES, SEE THE INITIAL PROGRAM-PART.
C
C
C     THE INPUT IS GIVEN IN MKSA-UNITS.
C     THAT IS METERS, KILOGRAMS, SECONDS AND AMPEREES, WITH THE
C     SECUNDARY UNITS VOLTS, FARADS, HENRY'S AND WATTS.
C
C
C
C     IADM    = GENERAL ADMINISTRATION PARAMETER.
C             =0, NO SPECIAL USE.
C             =1, ONLY THE SUMMARY PLOTS ARE PRINTED
C             =10, FREE-WHEEL DIODE CONDITIONS WILL BE PLOTTED.
C            =-1, END PROGRAM.
C
C     INPUT DESCRIBING  RECTIFIER AND TRANSFORMER.
C     --------------------------------------------
C
C                        M A I N   T R A N S F O R M E R
C
C       DIODE(S) 5   O---MMMMMMMM--*       *--MMMMMMMM---O DIODE(S) 2
C                                  I       I
C       DIODE(S) 3   O---MMMMMMMM--*       *--MMMMMMMM---O DIODE(S) 6
C                                  I       I
C       DIODE(S) 1   O---MMMMMMMM--*       *--MMMMMMMM---O DIODE(S) 4
C                                  I       I
C                                  I       I
C                                  I       *----MMMMMM---*
C                                  I                     *---- COMMON NODE
C                                  *----------MMMMM---*          (GROUND)
C
C                                        CURRENT DISTRIBUTION
C                                            TRANSFORMER
C
```

Program-Head. (continued).

```
C
C
C     NPHASE = 6 OR 12 PULSE COMBINATION.
C            GIVE 6 OR 12.
C
C     IDOBTH = SINGLE OR DOUBLE THYRISTOR ADMINISTR.
C            1=, SINGLE POLARITY
C            2=, DOUBLE POLARITY
C
C     IRECTF = SINGLE OR DOUBLE RECTIFIER ADMINISTR.
C            1=, POSITIVE VOLTAGES ARE DELIVERED TO THE LOAD.
C            0=, AC-VOLTAGES ARE DELIVERED TO THE LOAD.
C
C     VOLTRC = RECTIFIED PEAK VOLTAGE.
C
C     CUMAX  = MAX.PERMISSIBLE MEAN CURRENT
C
C     VOMAX  = MAX.PERMISSIBLE MEAN VOLTAGE.
C
C     CUMMFC = FACTOR ENTERING THE COMMUTATION EQUATION.
C              =0.0, NO COMMUTATION BETWEEN PHASES.
C
C
C     INPUT DESCRIBING THE LOAD.
C     --------------------------
C
C
C                                 AUX.LOAD    INDUCTANCE
C
C          0-----------*-------*-----WWWWW-----WWWWWW--*-------0   +
C                      I       I                       I
C       THYRISTOR      I       I                       I         LOAD
C       VOLTAGE        I       I                       I         VOLTAGE
C                      M       I                       M
C                      M       -                       M
C            RBASE     M     ( A )  DIODE      RLOAD   M
C                      M       I                       M
C                      M       I                       M
C                      I       I                       I
C                      I       I                       I
C          0-----------*-------*-----------------------*-------0
C
C                                 GROUND
C
C     IADMLO = ADMINISTRATION PARAMETER FOR LOAD.
C              =0, NO SPECIAL USE.
C              =1, A RC-FILTER IS PLACED OVER THE INDUCTANCE.
C                  THE NAMES ARE  RIND  AND  CIND.
C
C     RBASE  = BASE RESISTANCE.
C
C     RLOAD  = EXPERIMENTS RESISTANCE.
C
C     RAUX   = AUXILIARY LOAD.
C
C     IDIODE = FREE-WHEELLING DIODE.
C            0= NO DIODE
C            1=    DIODE
```

Program-Head. (continued).

```
C        IINDUC = ADMINISTRATIVE PARAMETER DESCRIBING INDUCTANCE.
C              =0. AIR INDUCTANCE. HEREAFTER GIVE ONE PARAMETER.
C                  PARAMETER NAME = AINDUC.
C              =1. IRON-AIRGAP INDUCTANCE. HEREAFTER GIVE  A TABLE.
C                GIVE UP TO 10 PAIRS OF CURRENT WITH CORRESPONDING
C                INDUCTANCE.FOR INCREASING CURRENTS. STARTING
C                WITH ZERO CURRENT.
C                  PARAMETER NAMES = AINDCU(10) AND AINDL (10).
C
C        INDUCTANCE PARAMETERS.
C
C        ***********************************************************
C
C        THIS IS EXAMPLES OF INPUT TO THE S L H T  LOOP.
C
C        0.25 MW   6 PHASE  POWER SUPPLY. NO FREE-WHEEL DIODE.
C        AND IRON-INDUCTANCE. FOR AIR-IND. GIVE IINDUC=0.AINDUC.
C
C&INL
C   IINDUC = 1
C  ,AINDCU(1) = 0.0     ,   AINDL (1) = 175.0E-6
C  ,AINDCU(2) = 250.0   ,   AINDL (2) = 150.0E-6
C  ,AINDCU(3) = 2501.0  ,   AINDL (3) =  34.0E-6
C  ,AINDUC      = 150.0E-6
C  ,RLOAD       = 0.016 , RAUX = 0.0
C  ,DALFA = 10.0,   IADM = 0
C  , IDIODE = 0,   IRECTF = 1
C,VOLTRC = 120.9,   CUMAX=2500.0,   VOMAX=100.0
C,NPHASE = 6
C,CUMMEC = 0.003
C    &END
C&INL      IADM=-1      &END
C
C        0.50 MW  12 PHASE (2 GROUPS). POWER SUPPLY. NO FREE-WHEEL DIODE.
C        AND IRON-INDUCTANCE. FOR AIR-IND. GIVE IINDUC=0.AINDUC.
C
C&INL
C  IINDUC = 1
C,AINDCU(1) = 0.0     ,   AINDL (1) = 175.0E-6
C,AINDCU(2) = 250.0   ,   AINDL (2) = 150.0E-6
C,AINDCU(3) = 2501.0  ,   AINDL (3) =  34.0E-6
C,AINDUC      = 150.0E-6
C ,RLOAD       = 0.016 , RAUX = 0.0
C,DALFA = 10.0,   IADM = 0
C, IDIODE = 0,   IRECTF = 1
C,VOLTRC = 120.9,   CUMAX=5000.0,   VOMAX=100.0
C,NPHASE = 12
C,CUMMEC = 0.003
C    &END
C&INL      IADM=-1      &END
C
C
```

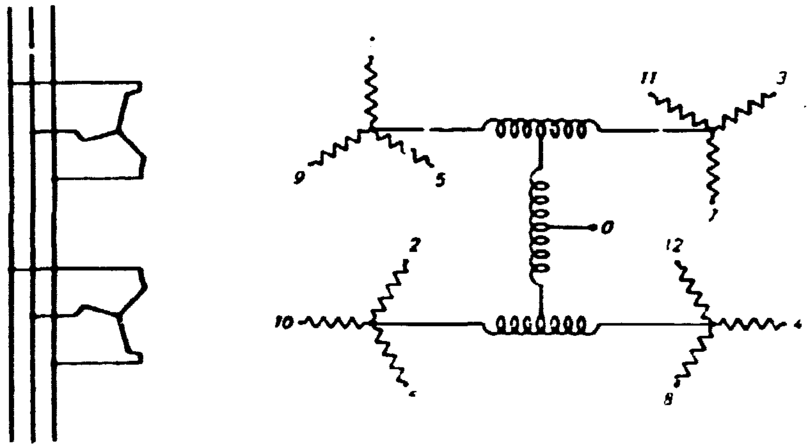


Fig. 1. Example of matched 12-pulse power supplies. With z-couplings in the primaries and 3 current distribution transformers.

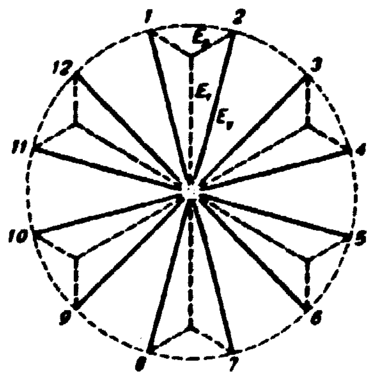


Fig. 2. Phase diagram for z-coupled primaries.

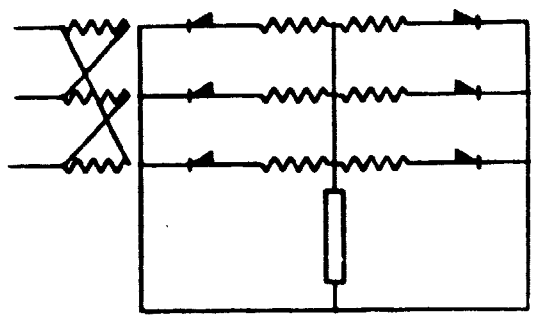


Fig. 3. Principle of 6-pulse single rectifier.

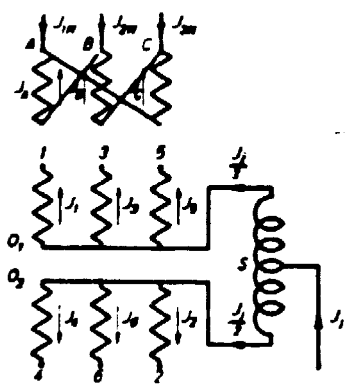


Fig. 4. Splitting of 6-pulse system into 2 independent 3-phase systems by current distribution transformer.

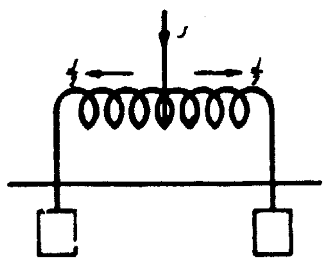


Fig. 5. Current distribution transformer.

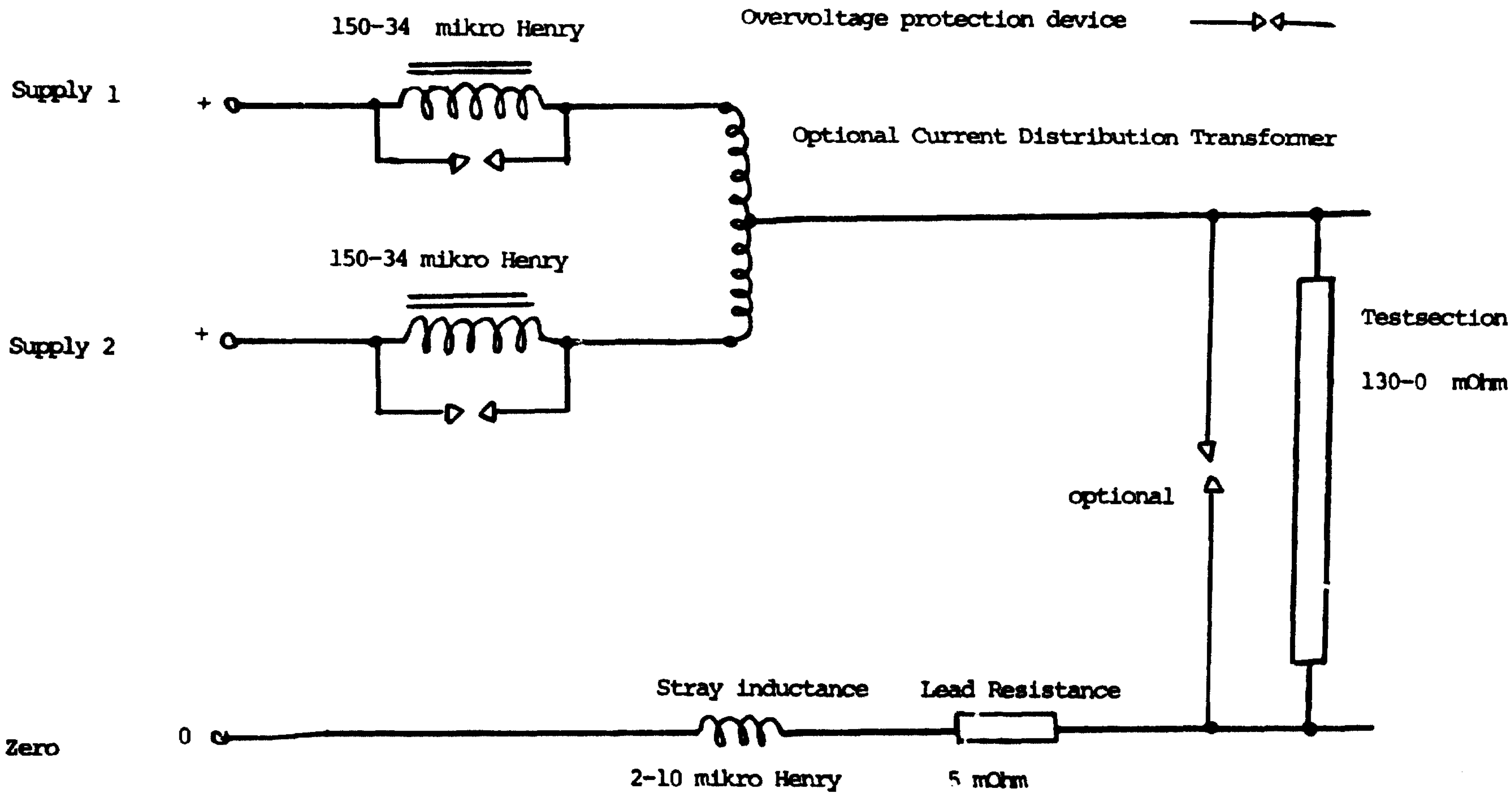
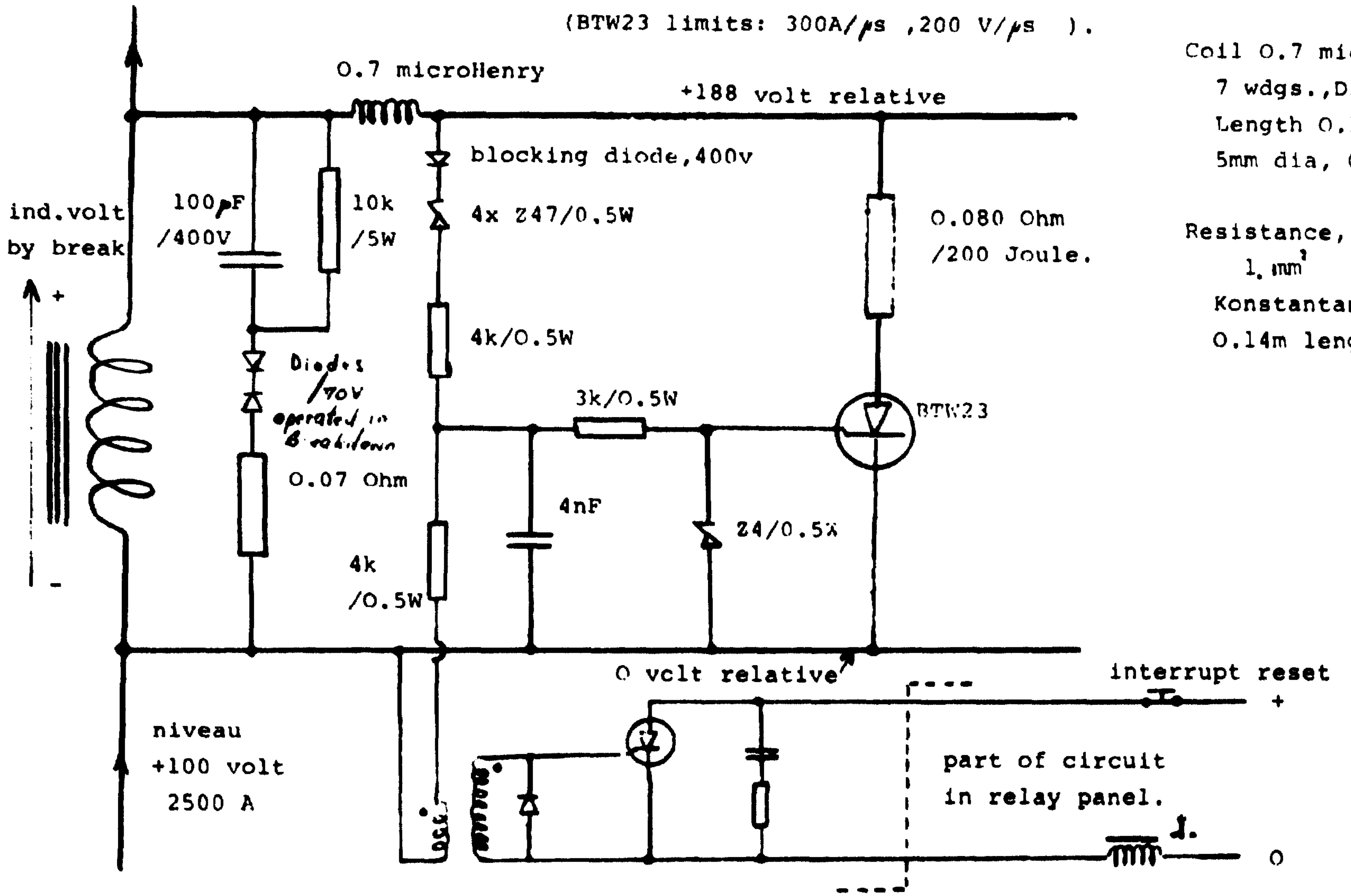


Fig. 6. Equivalent circuit of test section.



Coil 0.7 microHenry:
7 wdgs.,Diam. 0.05m
Length 0.15m
5mm dia, Cu wire.

Resistance, 0.080 Ohm:
$1, mm^2$
Konstantan
0.14m length.

Fig. 7. Overvoltage-Protection-Device, one-way.

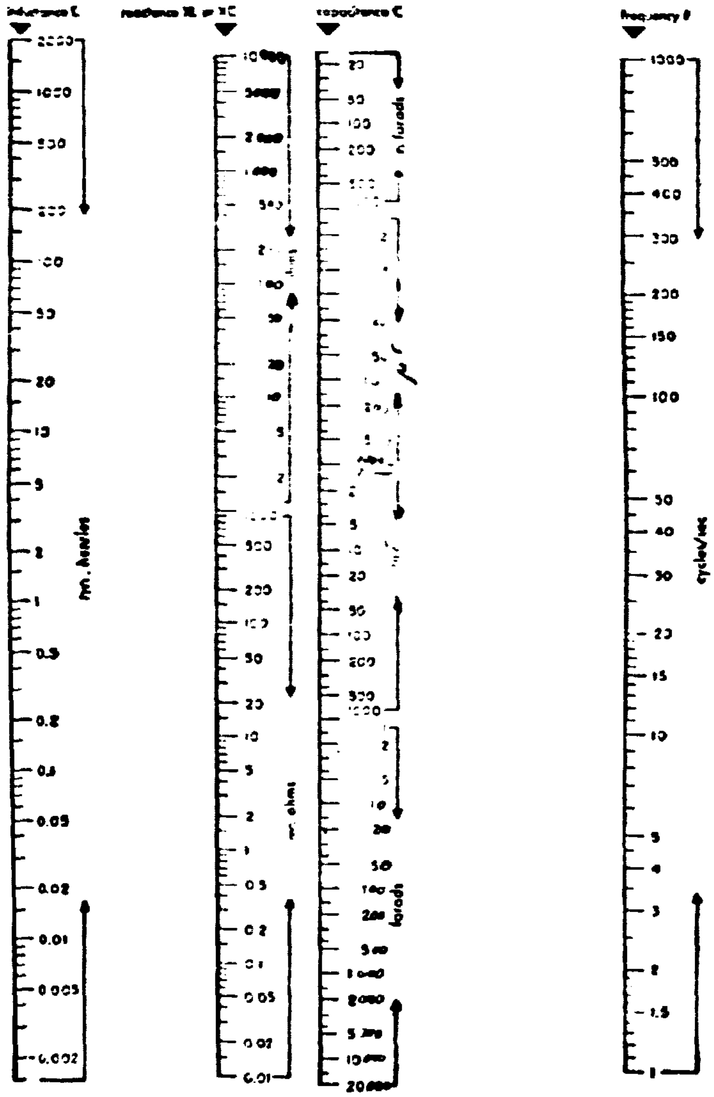


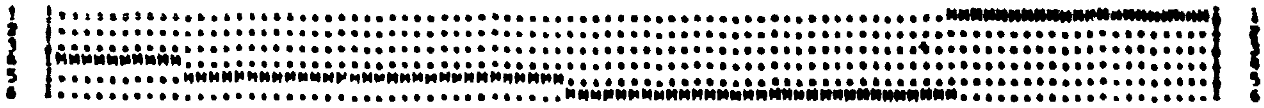
Chart covering 1 cycle to 1000 cycles.

Fig. 8. Reactance nomogram.

RESUME OF OVERALL CHARACTERISTICS AS A FUNCTION OF LOAD-RESISTANCE, UNDER THE GIVEN MAX. LIMITS

R	CURRENT	VOLTAGE	POWER(KW)	CHAR.TIME(R-L)	CH.FREQ.(R-L)	TIME(R-LMAX)
.50E-02	2500.00	12.50	31.25	.43E-01	23.370	.22E+00
.10E-01	2500.00	25.00	62.50	.21E-01	46.739	.11E+00
.15E-01	2500.00	37.50	93.75	.14E-01	70.109	.73E-01
.20E-01	2500.00	50.00	125.00	.11E-01	93.479	.55E-01
.25E-01	2500.00	62.50	156.25	.86E-02	116.849	.44E-01
.30E-01	2500.00	75.00	187.50	.71E-02	140.218	.37E-01
.35E-01	2500.00	87.50	218.75	.61E-02	163.588	.31E-01
.40E-01	2500.00	100.00	250.00	.53E-02	186.958	.27E-01
.45E-01	2222.22	100.00	222.22	.68E-02	148.078	.24E-01
.50E-01	2000.00	100.00	200.00	.75E-02	133.033	.22E-01
.55E-01	1818.18	100.00	181.82	.79E-02	126.519	.20E-01
.60E-01	1666.67	100.00	166.67	.81E-02	124.024	.18E-01
.65E-01	1538.46	100.00	153.85	.81E-02	123.742	.17E-01
.70E-01	1428.57	100.00	142.86	.80E-02	124.806	.16E-01
.75E-01	1333.33	100.00	133.33	.79E-02	126.752	.15E-01
.80E-01	1250.00	100.00	125.00	.77E-02	129.306	.14E-01
.85E-01	1176.47	100.00	117.65	.76E-02	132.296	.13E-01
.90E-01	1111.11	100.00	111.11	.74E-02	135.612	.12E-01
.95E-01	1052.63	100.00	105.26	.72E-02	139.175	.12E-01
.10E+00	1000.00	100.00	100.00	.70E-02	142.931	.11E-01
.11E+00	952.38	100.00	95.24	.68E-02	146.842	.10E-01
.11E+00	909.09	100.00	90.91	.66E-02	150.877	.10E-01
.12E+00	869.57	100.00	86.96	.65E-02	155.014	.96E-02
.12E+00	833.33	100.00	83.33	.63E-02	159.236	.92E-02
.13E+00	800.00	100.00	80.00	.61E-02	163.528	.88E-02
.13E+00	769.23	100.00	76.92	.60E-02	167.881	.85E-02
.14E+00	740.74	100.00	74.07	.58E-02	172.286	.81E-02
.14E+00	714.29	100.00	71.43	.57E-02	176.735	.79E-02
.14E+00	689.66	100.00	68.97	.55E-02	181.222	.76E-02
.15E+00	666.67	100.00	66.67	.54E-02	185.743	.73E-02
.15E+00	645.16	100.00	64.52	.53E-02	190.294	.71E-02
.16E+00	625.00	100.00	62.50	.51E-02	194.871	.69E-02
.16E+00	606.06	100.00	60.61	.50E-02	199.471	.67E-02
.17E+00	588.24	100.00	58.82	.49E-02	204.091	.65E-02
.17E+00	571.43	100.00	57.14	.48E-02	208.730	.63E-02
.18E+00	555.56	100.00	55.56	.47E-02	213.386	.61E-02
.18E+00	540.54	100.00	54.05	.46E-02	218.057	.59E-02
.19E+00	526.32	100.00	52.63	.45E-02	222.741	.58E-02
.19E+00	512.82	100.00	51.28	.44E-02	227.437	.56E-02
.20E+00	500.00	100.00	50.00	.43E-02	232.145	.55E-02
.20E+00	487.80	100.00	48.78	.42E-02	236.863	.54E-02
.21E+00	476.19	100.00	47.62	.41E-02	241.590	.52E-02
.21E+00	465.12	100.00	46.51	.41E-02	246.326	.51E-02
.22E+00	454.55	100.00	45.45	.40E-02	251.070	.50E-02
.22E+00	444.44	100.00	44.44	.39E-02	255.822	.49E-02
.23E+00	434.78	100.00	43.48	.38E-02	260.580	.48E-02
.23E+00	425.53	100.00	42.55	.38E-02	265.344	.47E-02
.24E+00	416.67	100.00	41.67	.37E-02	270.114	.46E-02
.24E+00	408.16	100.00	40.82	.36E-02	274.890	.45E-02
.25E+00	400.00	100.00	40.00	.36E-02	279.670	.44E-02

Fig. 9. Resume of characteristics as function of load



LOOP RESULT FOR IGNITION ANGLE = 140.0000

LOAD

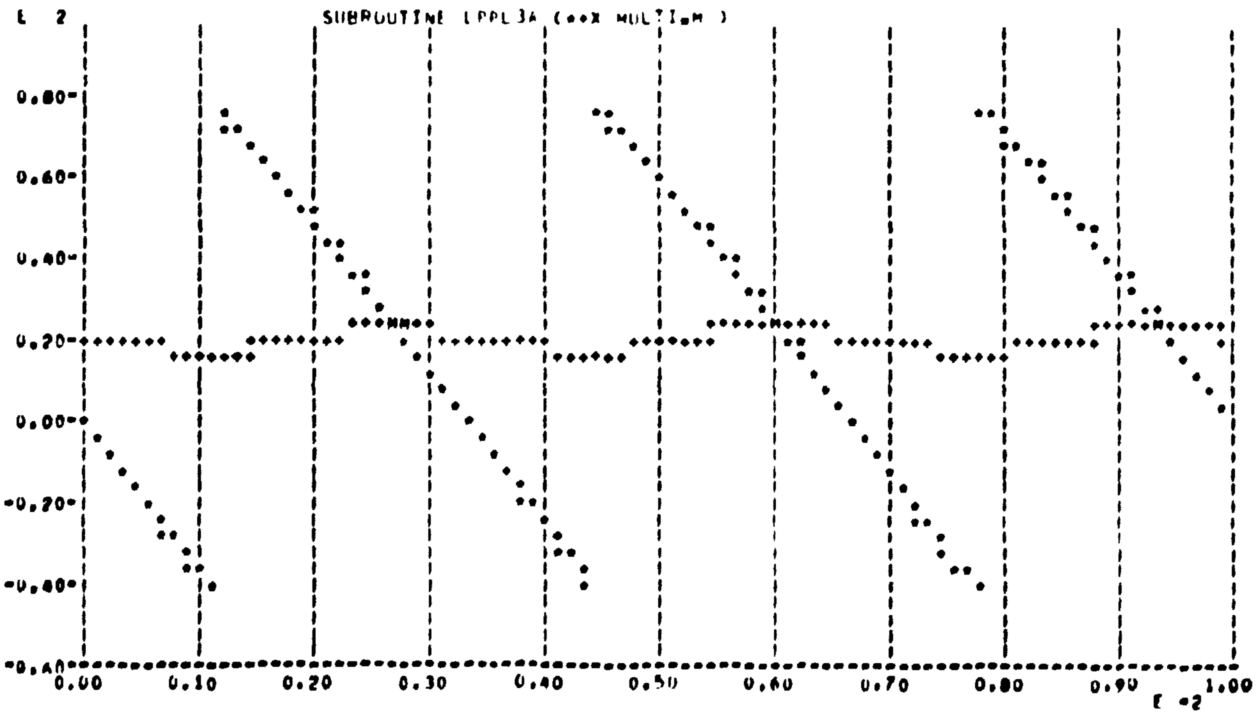
VOLT(-)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(-)KW	POWER(+)KW	VEFF AC (-)	VEFF AC (+)
20.203	20.203	505.073	10.204	40.002	10.319	35.019	2.146

TOTAL LOAD

VOLT(-)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(-)KW	POWER(+)KW	VEFF AC (-)	VEFF AC (+)
20.203	20.203	505.073	10.204	40.002	10.319	35.019	2.146

AUXILIARY LOAD

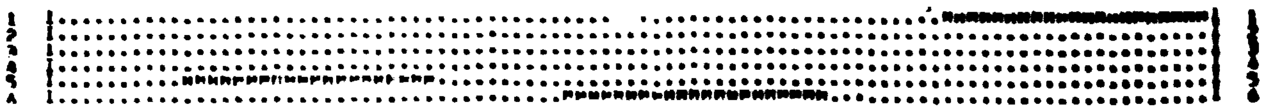
VOLT(-)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(-)KW	POWER(+)KW	VEFF AC (-)	VEFF AC (+)
0.000	0.000	505.073	0.000	0.000	0.000	0.000	0.000



IGNITION ANGLE = 140.0000 HALF PERIODE OF VOLTAGES BEFORE (-) AND AFTER (+) FILTERING

Fig. 10. Results 140 deg. ignition RLOAD = 0.040,-diode

ORDER OF IGNITION



L O O P   R E S U M E   FOR IGNITION ANGLE = 140.0000

LOAD

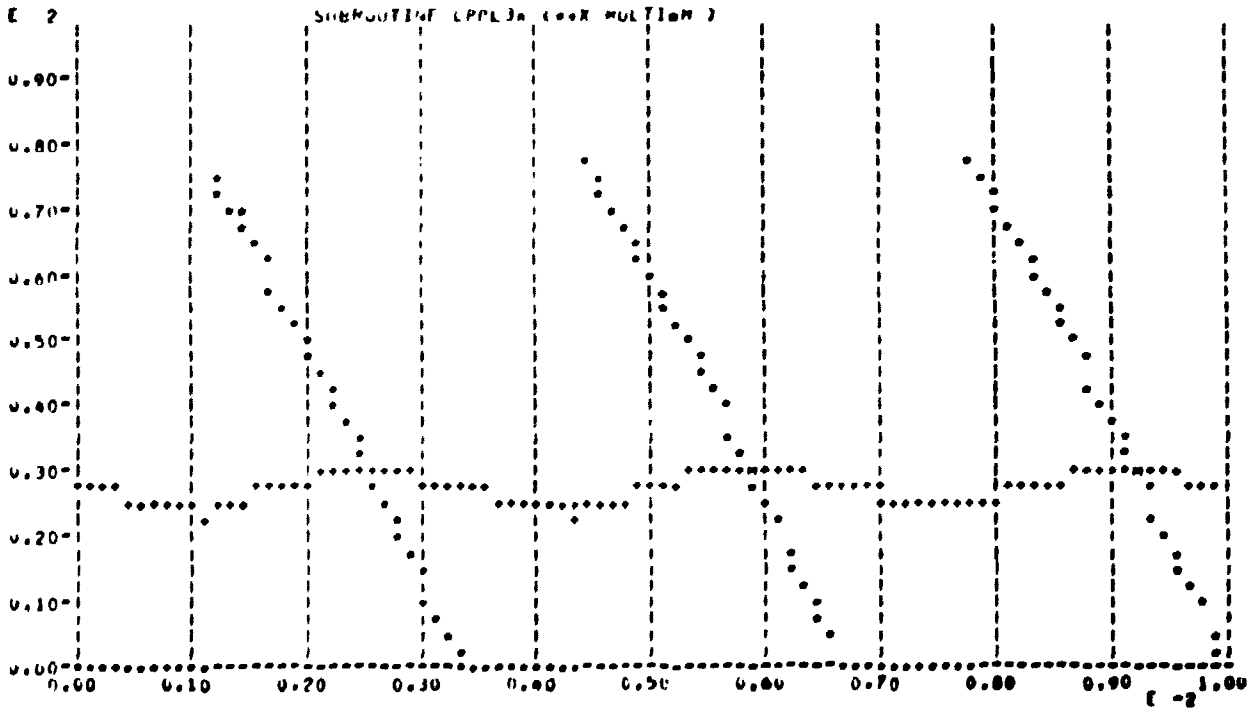
VOLT(+)	VOLT(-)	CURRENT	DC-POWER(KW)	POWER(+)KW	POWER(-)KW	VEFF AC (+)	VEFF AC (-)
27.111	27.111	677.770	18.375	36.090	18.462	26.620	1.865

TOTAL LOAD

VOLT(+)	VOLT(-)	CURRENT	DC-POWER(KW)	POWER(+)KW	POWER(-)KW	VEFF AC (+)	VEFF AC (-)
27.111	27.111	677.770	18.375	30.090	18.462	26.620	1.865

AUXILIARY LOAD

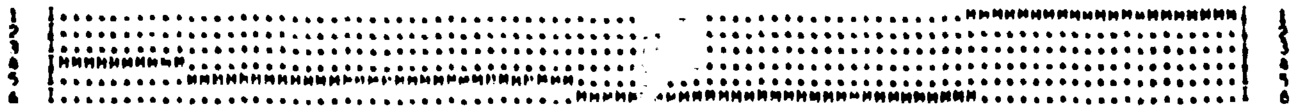
VOLT(+)	VOLT(-)	CURRENT	DC-POWER(KW)	POWER(+)KW	POWER(-)KW	VEFF AC (+)	VEFF AC (-)
0.000	0.000	677.770	0.000	0.000	0.000	0.000	0.000



IGNITION ANGLE = 140.0000 HALF PERIODE OF VOLTAGES BEFORE (+) AND AFTER (-) FILTERING

Fig. 11. Results 140 deg. ignition RLOAD = 0.040,+diode

ORDER OF IGNITION



G O U P   R E S U M E   FOR IGNITION ANGLE = 140.0000

LOAD

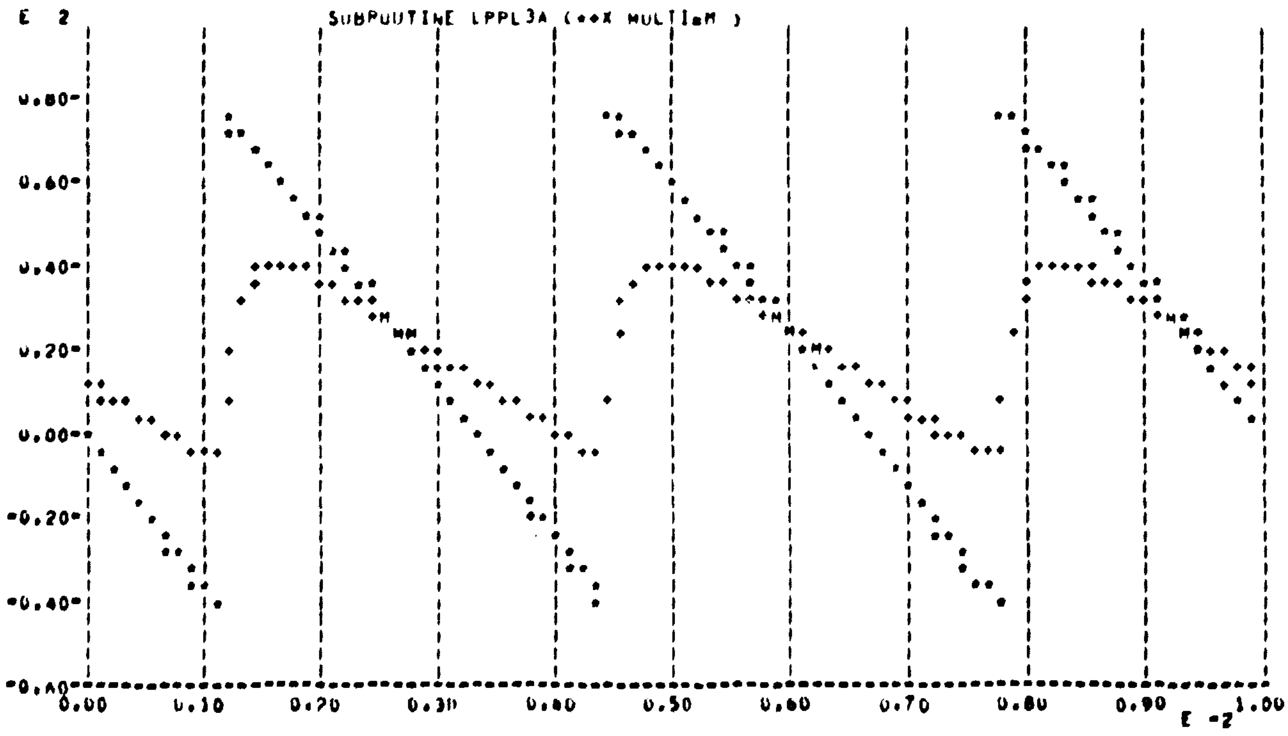
VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (*)	VEFF AC (+)
20.203	20.203	20.203	0.408	1.634	0.621	35.019	14.582

TOTAL LOAD

VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (*)	VEFF AC (+)
20.203	20.203	20.203	0.408	1.634	0.621	35.019	14.582

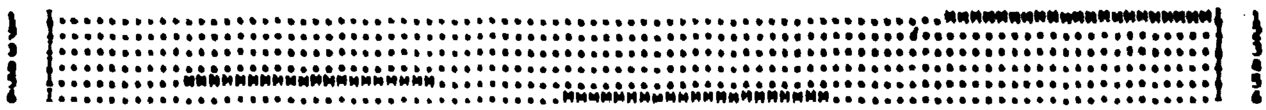
AUXILIARY LOAD

VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (*)	VEFF AC (+)
0.000	0.000	20.203	0.000	0.000	0.000	0.000	0.000



IGNITION ANGLE = 140.0000 HALF PERIODE OF VOLTAGES BEFORE (*) AND AFTER (+) FILTERING

Fig. 12. Results 140 deg. ignition RLOAD = 1.,-diode



LOOP RESUME FC. IGNITION ANGLE = 140.0000

LOAD

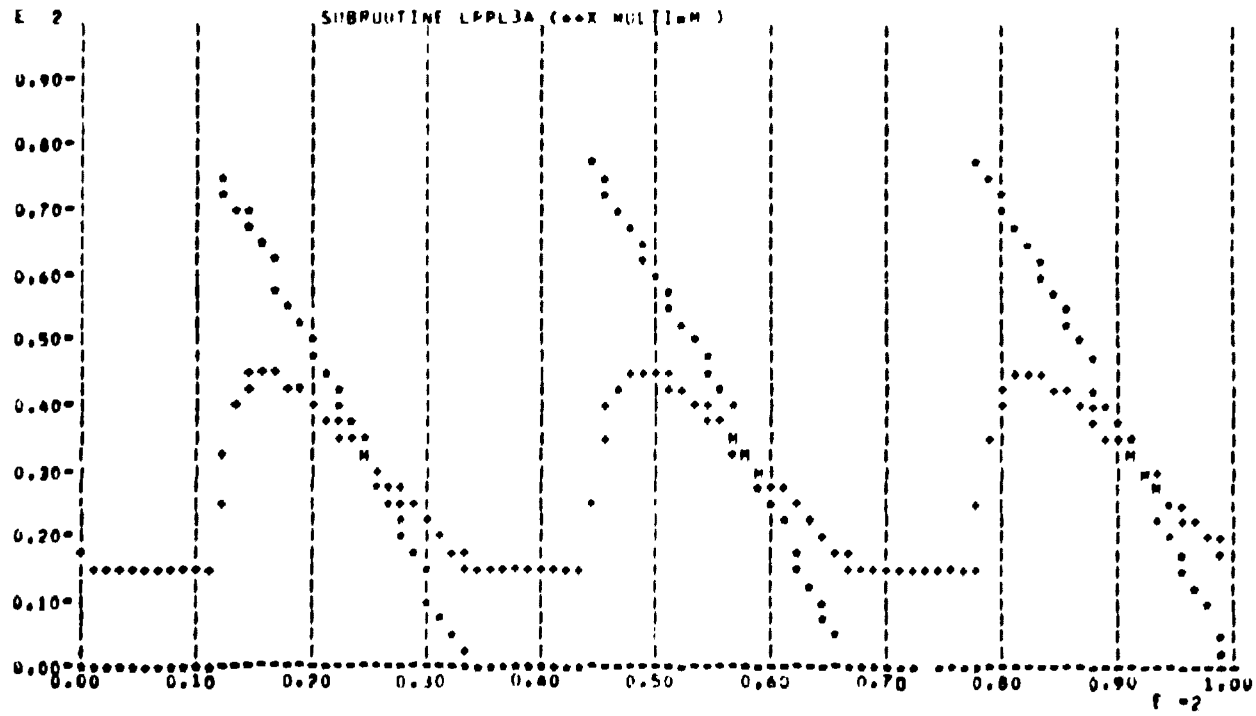
VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (+)	VEFF AC (*)
27.111	27.111	27.111	0.735	1.444	0.867	26.620	11.491

TOTAL LOAD

VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (+)	VEFF AC (*)
27.111	27.111	27.111	0.735	1.444	0.867	26.620	11.491

AUXILIARY LOAD

VOLT(*)	VOLT(+)	CURRENT	DC-POWER(KW)	POWER(*)KW	POWER(+)KW	VEFF AC (+)	VEFF AC (*)
0.000	0.000	27.111	0.000	0.000	0.000	0.000	0.000



IGNITION ANGLE = 140.0000 HALF PERIODE OF VOLTAGES BEFORE (*) AND AFTER (+) FILTERING

R= 1. Ohm
+ Diode

Fig. 13 a Results 140 deg. ignition RLOAD = 1.,+diode

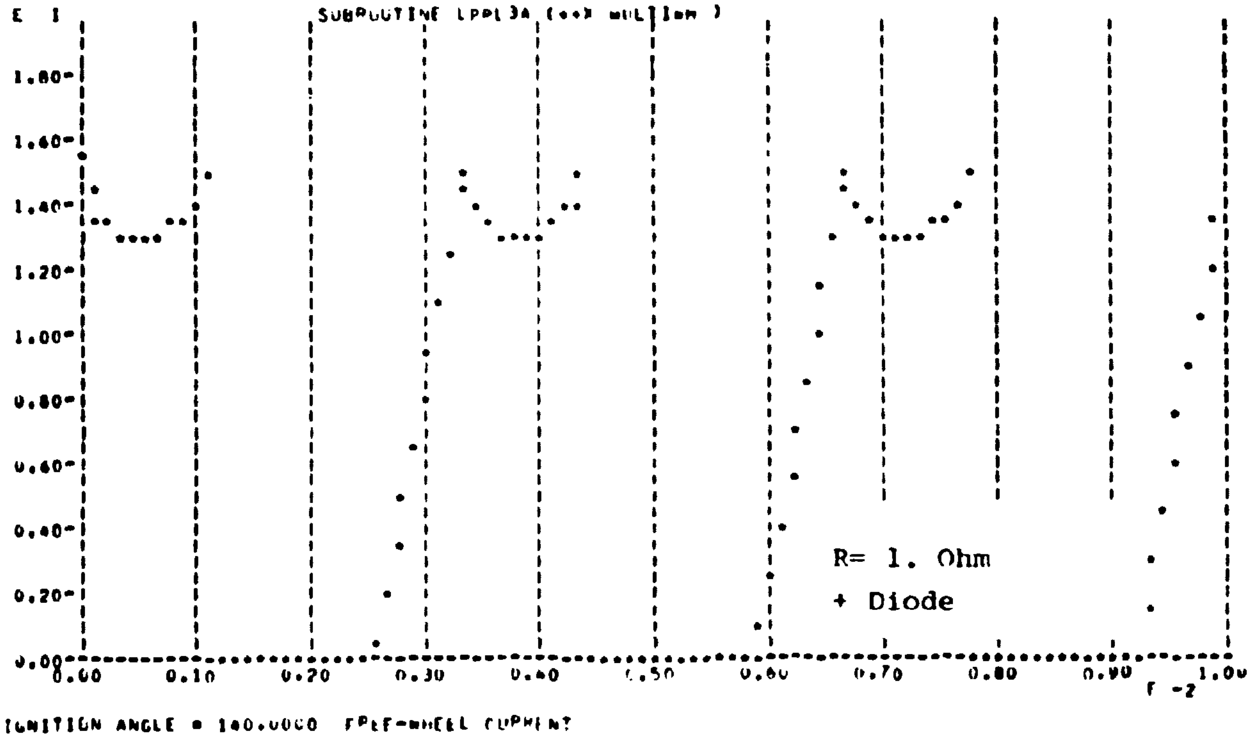


Fig. 13 b Results 140 deg. ignition RLOAD = 1.,+diode

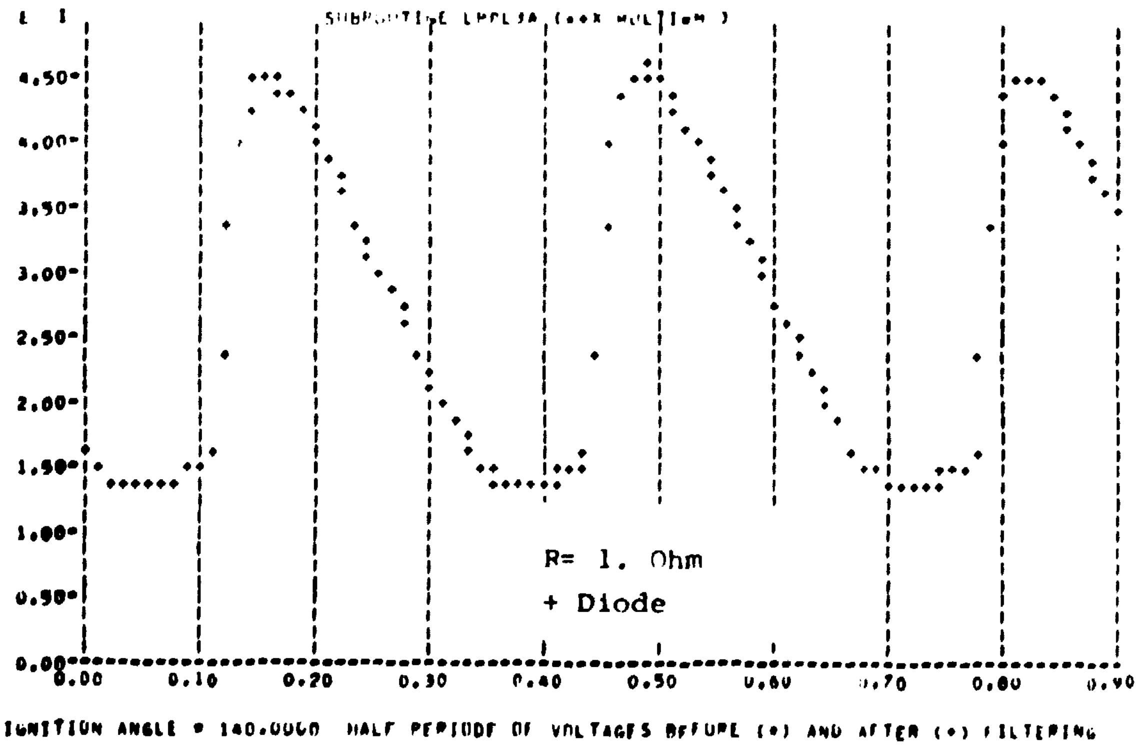


Fig. 13 c Results 140 deg. ignition RLOAD = 1.,+diode

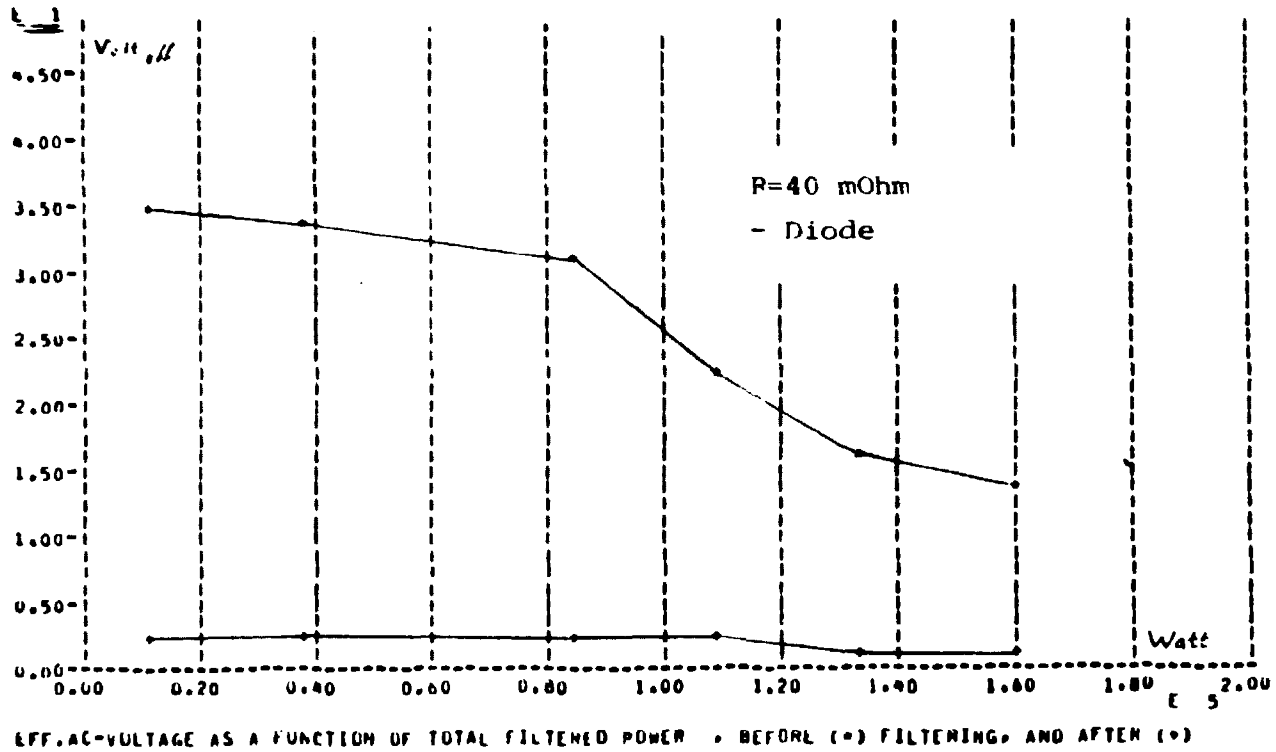


Fig. 14. Eff. AC-voltage before and after filter 0.040,-diode

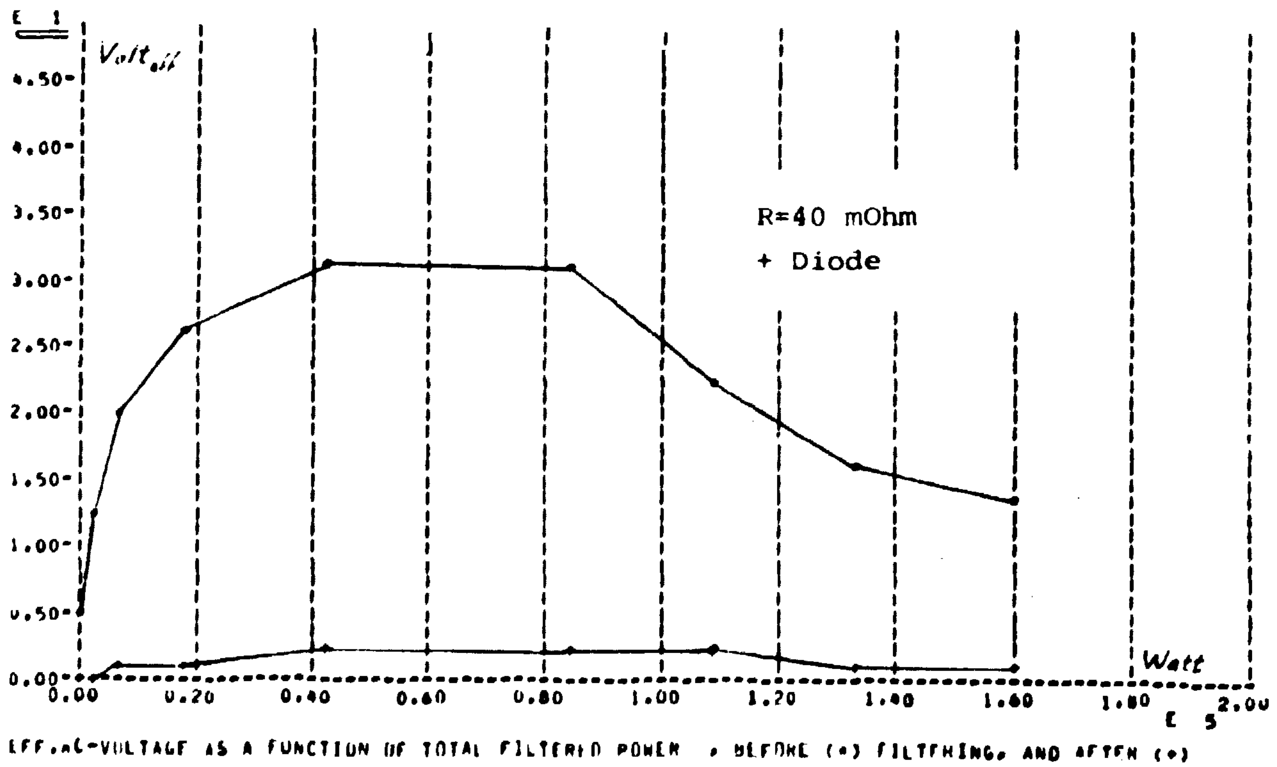
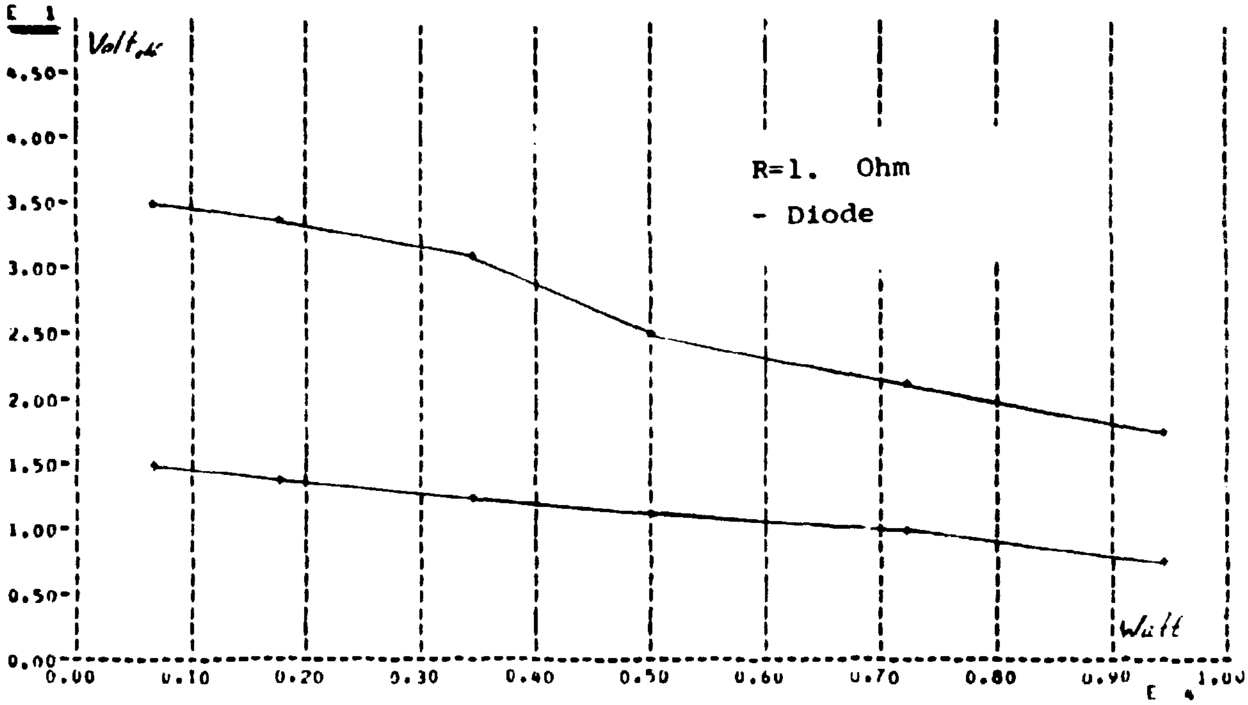
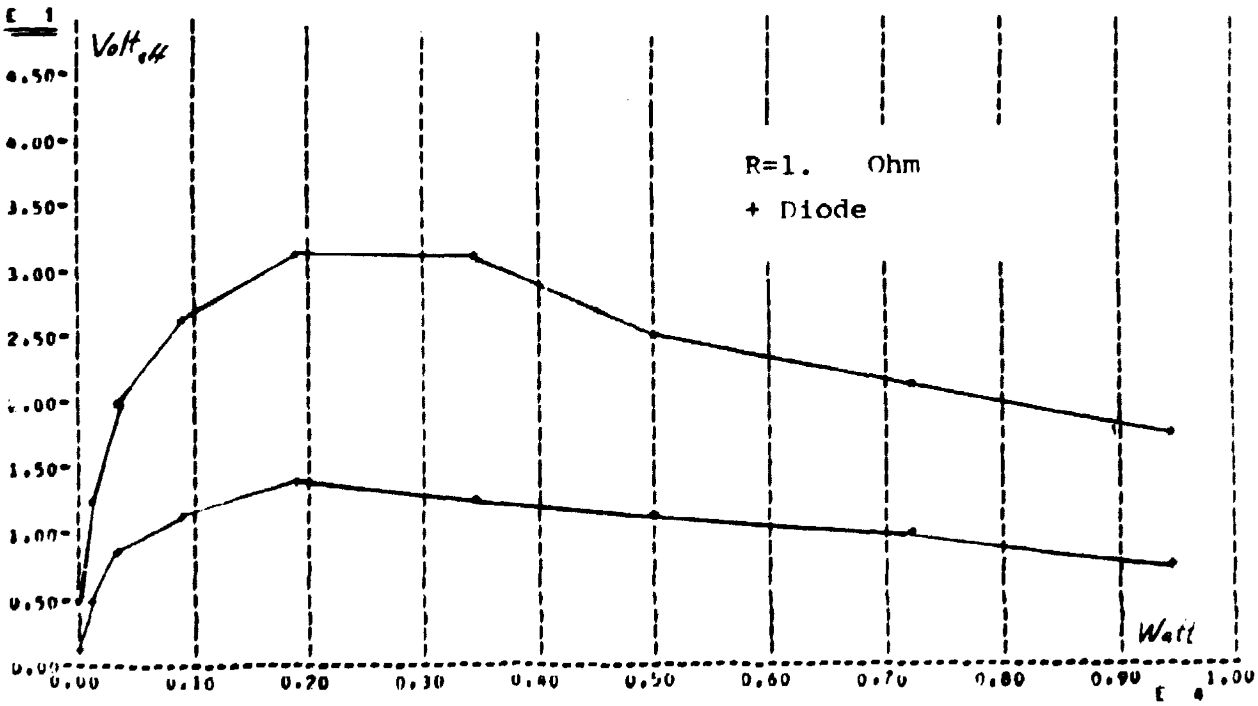


Fig. 15. Eff. AC-voltage before and after filter 0.040,+diode



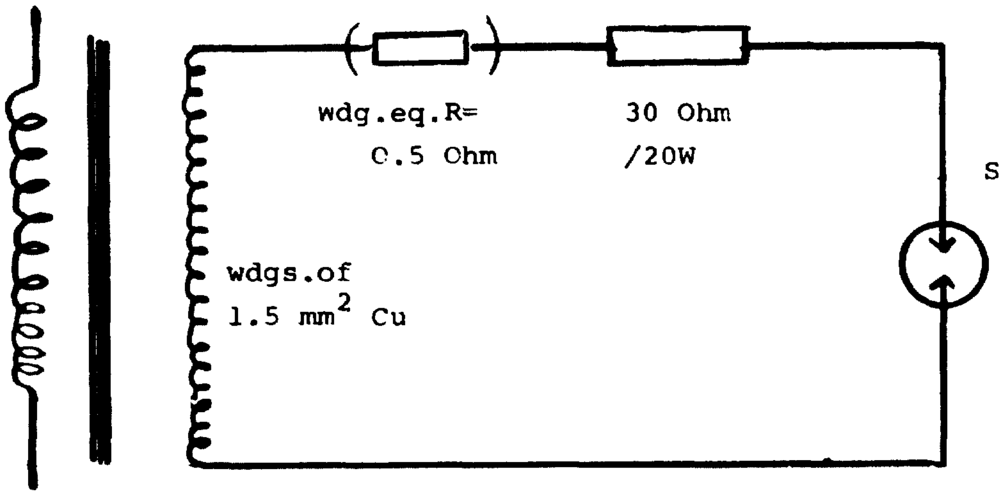
EFF.AC-VOLTAGE AS A FUNCTION OF TOTAL FILTERED POWER , BEFORE (+) FILTERING, AND AFTER (+)

Fig. 16. Eff. AC-voltage before and after filter 1.0,-diode



EFF.AC-VOLTAGE AS A FUNCTION OF TOTAL FILTERED POWER , BEFORE (+) FILTERING, AND AFTER (+)

Fig. 17. Eff. AC-voltage before and after filter 1.0,+diode



Siemens : Es sich 35a
(350 V arc, 550 V ign.,
20 kA peak).
Holder: Q 06554-A2-A1

6 wdgs — Primary Winding

18 wdgs — Secondary auxilliary Winding

Timeconstant for discharge= 4msec

Ignition voltage,primary = 183± 25 V

Extinguishing volt,prim. = 117± 17 V

Inner resistance for discharge tube at transient begin = 1.4 Ohm

Fig.18 . Overvoltage protection device. (later version).