CENTRAL ELECTRICITY REGULATORY COMMSSION
3rd & 4th Floor, Chanderlok Building, 36 Janpath, New Delhi 110 001
(Tele No.23353503 FAX No.23753923)

Petition No. 180/MP/2017 **Dated the 4th July, 2018**

Notice

Subject: Petition under Section 41 of the Electricity Act, 2003 read with Central Electricity Regulatory Commission (Sharing of Revenue derived from utilization of transmission assets for other business) Regulations, 2007 for intimation to engage in other business for optimum utilization of transmission assets.

The Commission vide Record of Proceedings for the hearing dated 11.1.2018 constituted a committee under the Chairmanship of Chief (Finance) with Chief (Engineering) and Chief (Law) of the Commission as members to look into the technical and financial aspects of the project by considering how the Petitioner would like to share its revenue with the beneficiaries. In this regard, discussion was held by the Committee on 25.1.2018. Pursuant to the discussion, the Petitioner has submitted the Financial Proposal including Revenue Sharing model with the beneficiaries along with justification and Technical Paper.

2. A copy of the Financial Proposal and Technical Paper is enclosed for comments.

3. The Petition shall be listed for hearing in due course.

04/07/18

(Sanoj Kumar Jha)
Secretary

पावर ग्रिड कारपोरेशन ऑफ इंडिया लिमिटेड
(भारत सरकार का उद्यम)
POWER GRID CORPORATION OF INDIA LIMITED
(A Government of India Enterprise)
केन्द्रीय कार्यालयः "सौदामिनी" प्लॉट सं. 2, सैक्टर–29, गुडगाँव–122 001, (हरियाणा) दूरभाषः 0124-2571700-719, फैक्स : 0124-2571
"Saudamini" Plot No. 2, Sector-29, Gurgaon-122 001, (Haryana) Tel. : 0124-2571700-719, Fax : 0124-2571762, Web.: www.powergridindia.co
CIN : L40101DL1989GOI03812

C/RC/180_MP_2017 03/05/2018

Shri M. K. Anand
Chief (Finance),
Central Electricity Regulatory Commission
3rd – 4th Floor, Chandralok Building,
36, Janpath, New Delhi – 110 001

विषय- Intimation to engage in other business for optimum utilization of transmission assets for offering POWERGRID's Tower Infrastructure & Power Supply drawn from POWERGRID's EHV Lines to Telecom Tower Infrastructure providers (TTIPs)/ Telecom Service Providers (TSPs) for installation & use of Telecom Antenna/BTS. [Petition No. 180/MP/2017]
- Submission of Financial Proposal thereof reg.

Respected Sir,

This is in reference CERC's Record of Proceedings (RoP) dated 17/01/2018 in petition no. 180/MP/2017 and subsequent meeting held on 25/01/2018 on the subject matter.

In line with the discussions held during the meeting on 25/01/2018, the Financial Proposal of the subject project including Revenue Sharing model with beneficiaries along with justification and Technical Paper for use of Power induced in the earth wire is attached herewith for ready reference.

Thanking you,

Yours faithfully,

(Abhay Choudhary)
Executive Director (Commercial & Reg. Cell)

Copy for information please:
Chief (Engineering), CERC
Chief (Law), CERC

Financial Proposal
For
Utilization of Transmission Line Infrastructure for Telecom Business
Petition No. 180/MP/2017 and ROP dtd.11.01.20128

1) Background

Digital India Program of Govt. of India envisages universal mobile connectivity. The "Digital India" is a flagship programme of the Government of India with a vision to transform India into a digitally empowered society and knowledge economy. Also Government of India has approved the e-Kranti programme recently with the vision of "Transforming e-Governance for Transforming Governance" by utilizing the emerging technology like Mobile, Cloud e.t.c. To achieve the goal of "Digital India" program, universal mobile connectivity is one of the main pillar. India has more than 50,000 villages without mobile connectivity and countless sparsely populated areas with poor mobile connectivity. Further, TRAI has emphasized for reduction in carbon footprint through reducing use of DG set at mobile tower locations and utilizing alternate possible energy source including renewables.

Major constraints for improving the mobile connectivity are

- Mobile operators need to incur high capex to setup Towers
- Non-availability of reliable power supply source making it dependent on DG power resulting into high operational cost
- Difficulty to lease land and manage the Mobile set-up due to its remoteness

These constraints can be overcome to a large extent if POWERGRID's transmission towers are used for mounting the telecom antennas, Base Transceiver System (BTS) and associated auxiliary power supply equipment for mobile communication. This can be achieved by constructing a platform on the transmission line tower (at 7-8 meters above ground) itself to house this equipment(Photo attached **Annex-I**). Further, reliable power supply can also be provided for operation for BTS equipment from transmission line itself by adopting suitable technologies available. Such an arrangement can also protect the BTS and ancillary equipment from flood like disasters.

2) <u>Methodology for Use of Induced Power in Earth Wire</u>

Two earth wires are provided at the top of 765kV & 400kV transmission lines for lightening protection. These earth wires get continuously charged through capacitive coupling with live conductors. This energy is continuously discharged through grounding of earth wire (E/W) on each transmission line towers. This discharge current or energy can be utilized through suitable rating Power PT, to provide reliable power to BTS, which otherwise is going into ground through earthling at each tower location.

Result of Simulation study attached at **Annex-II.** The published technical papers to draw the power from earthwire are attached at **Annexure[1] -III**.

A demo set-up has been established at POWERGRID Jhatikara Sub-station by Utilizing Jhatikara-Mundka 400 KV D/C Line of POWERGRID and working satisfactory since 18.06.2017.

3) <u>Benefits (from E/W based Solution)</u>

- Energy which otherwise was going as waste to earth can be smartly tapped & put to use.

- Failure of MV equipment (connected to E/W) doesn't affect the operation/availability of EHV line.

- No requirement of land as all telecom equipment including battery bank can be kept on a suitable platform on T/L tower itself.

- Providing tower with reliable power in remote areas of the country to TSPs for installing their telecom equipment to provide reliable communication fulfilling the Dream of Digital India.

- By providing reliable 24x7 power supply leading to removal of DG set from Telecom Towers thereby reducing carbon footprint, one of the major priorities of TRAI and GoI

4)* Marketing *Strategy

M/s KPMG was assigned for preparing the business case to utilize the transmission towers for telecom utility. They have come up with these observations.

- POWERGRID has ~ 2,50,000 Transmission Towers out of which most are located in rural area.

- **Low voltage line Limitation:** Only 400KV D/C and above voltage lines are useful to provide the required Power for BTS equipment's through isolated the earthwire. Also lower voltage line heights are not suitable for installation of Mobile Antenna. Due to this limitation, only 2,00,000 Transmission Tower are useful.

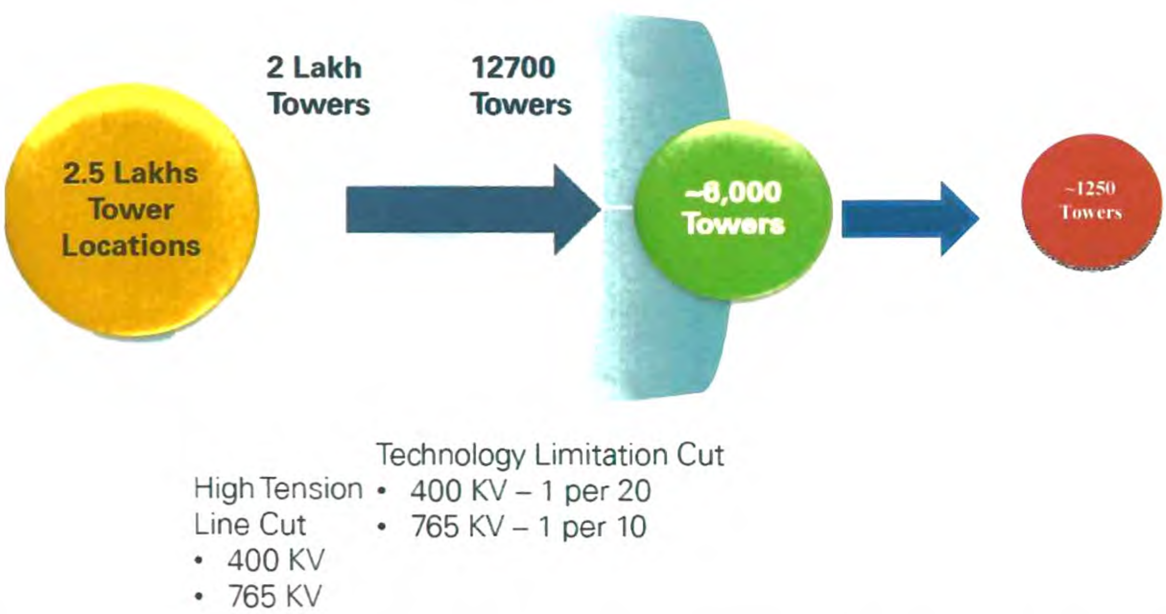
- **Technology Limitation:** As per industry feedback approximately 8KW power is required to run the BTS System. For getting the 8KW Power, it is required to isolate

[1] ESKOM, South Africa, for Tapping Power from the Overhead Ground Wire of a High-Voltage Transmission Line. (Leonard Bolduc, Yves Brissette, Jean Lemay, Gilbert Sybille; Hydro-Quebec Research Institute(IREQ)

the Earthwire from 20 Towers on 400KV D/C Lines and from 10 towers on 765KV lines. Therefore only 1 Location is usable out of 20 Tower in 400KV D/C Line and 10 Towers in 765 KV Lines. Due to technological limitation only 12,700 towers are useful.

- **Minimum revenue per Tower:** Further, only those towers are financial viable to Mobile Operator having minimum population 3500, therefore out of 12,700 towers, those geographies with a population of min. 3500 are around 6000 Nos.

- Further as per KPMG assessment, the salable location will vary from 1250 to 6000 Nos.



POWERGRID can offer the service directly to telecom operators like Airtel, Vodafone, Jio etc. or to telecom infrastructure players like Indus, Bharti Infratel who will in turn give it to telecom players.

5) Financial Proposal

a. **Capex :** Capex/Location (in Lacs): (Detailed break-up attached at **Annex-IV**)

Sr.	Capex Expenditure	Life of Asset	Asset details
i.	Rs.15.30 Lacs	15 Year	Power PT, LA and other Power equipment
ii.	Rs.1.9 Lacs	7.5 Year	Battery Charger with remote monitoring
iii.	Rs.2.45 Lacs	5 Year	Battery Bank

b. Operational Expenses :

Annual operational expenses/Location : Rs.1.12 Lacs (Rs.9325/Month). Details attached **Annex-V.**

c. **Revenue** :

Being the new entry of POWERGRID in market and present financial conditions of Telecom industries, M/s KPMG recommended the following rentals/Month/Location viz industry offer-

Parameter	Industry Average	BSNL	POWERGRID (Mobile Operator)
Urban Rent- Single Tenant	56000	51750	50000
Rural Rent- Single Tenant	56000	50000	45000
Urban Rent- Second Tenant	49000	48075	45000
Rural Rent- Second Tenant	49000	46500	40000
Urban Rant Third Tenant	41000	44768	
Rural Rant Third Tenant	41000	43350	

Note: 1. The rents are including all the expenses including energy cost.
2. Urban : Rural Tower Split ratio is 10:90 % and double tenancy of 100% in urban area and 5% in rural area.

d. Other consideration as per KPMG recommendation

I. Agreement with TSP`s will be for 15 Years

II. Debt : Equity = 70:30

III. Interest on Loan @ 9%

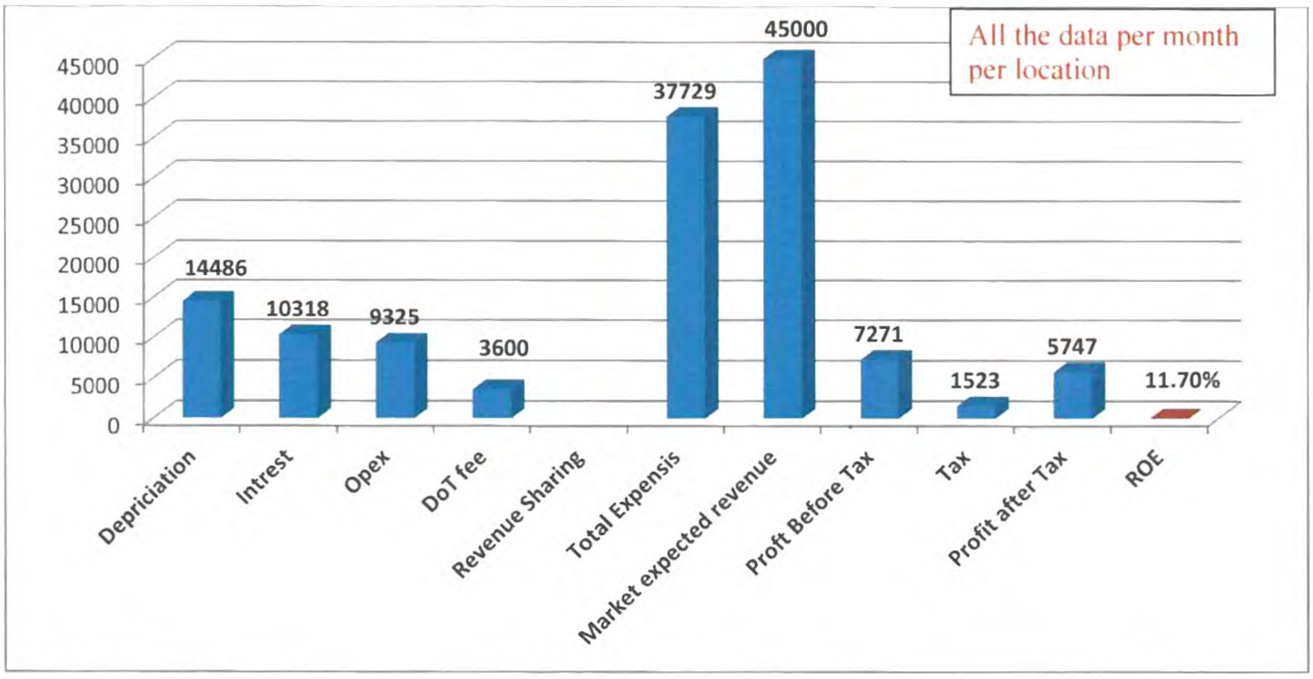
IV. Taxes @ 20.96%

V. DoT license fee on revenue @ 8 % on revenue

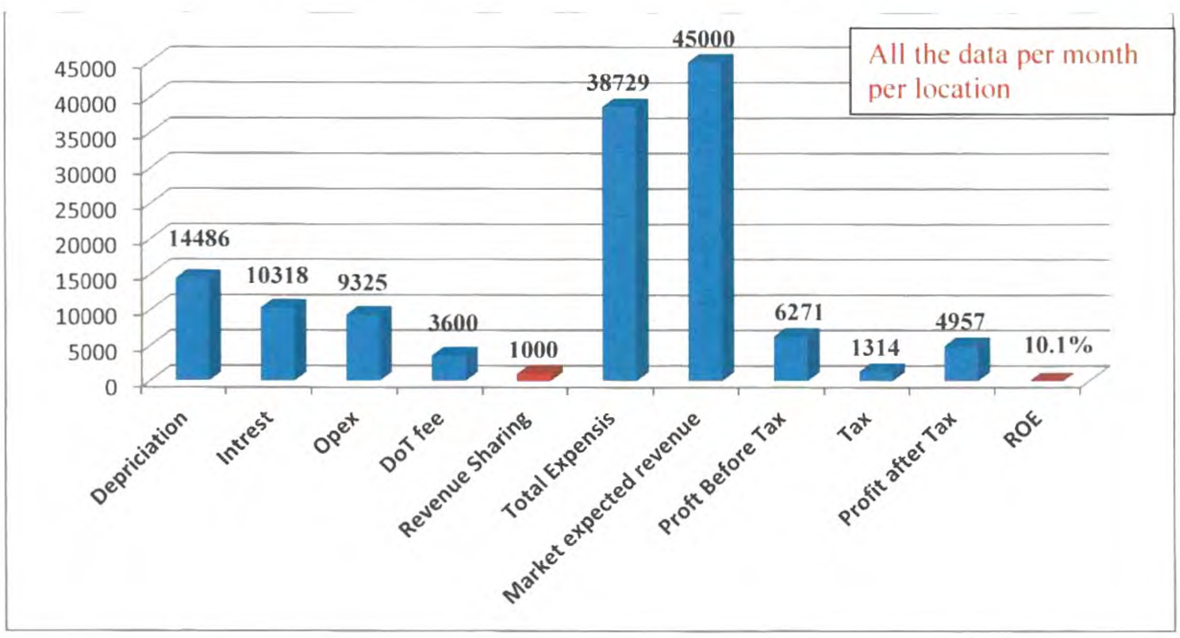
VI. **Depreciation:** Rs. 14,486/Location (Considering the life of assets the depreciation rates are (i) 6.7% for equipment with Life of 15 Years, (ii)13.3 % for equipment with Life of asset 7.5 Years and (iii) 20% for equipment with Life of asset 5 Years.)

e. **Considering all the tower in rural area with single tenancy, the RoE calculation/Location–**

I. Without sharing revenue with beneficiaries



II. Sharing about 13.5% of PBT (Rs.1000/Month/Location) with beneficiaries



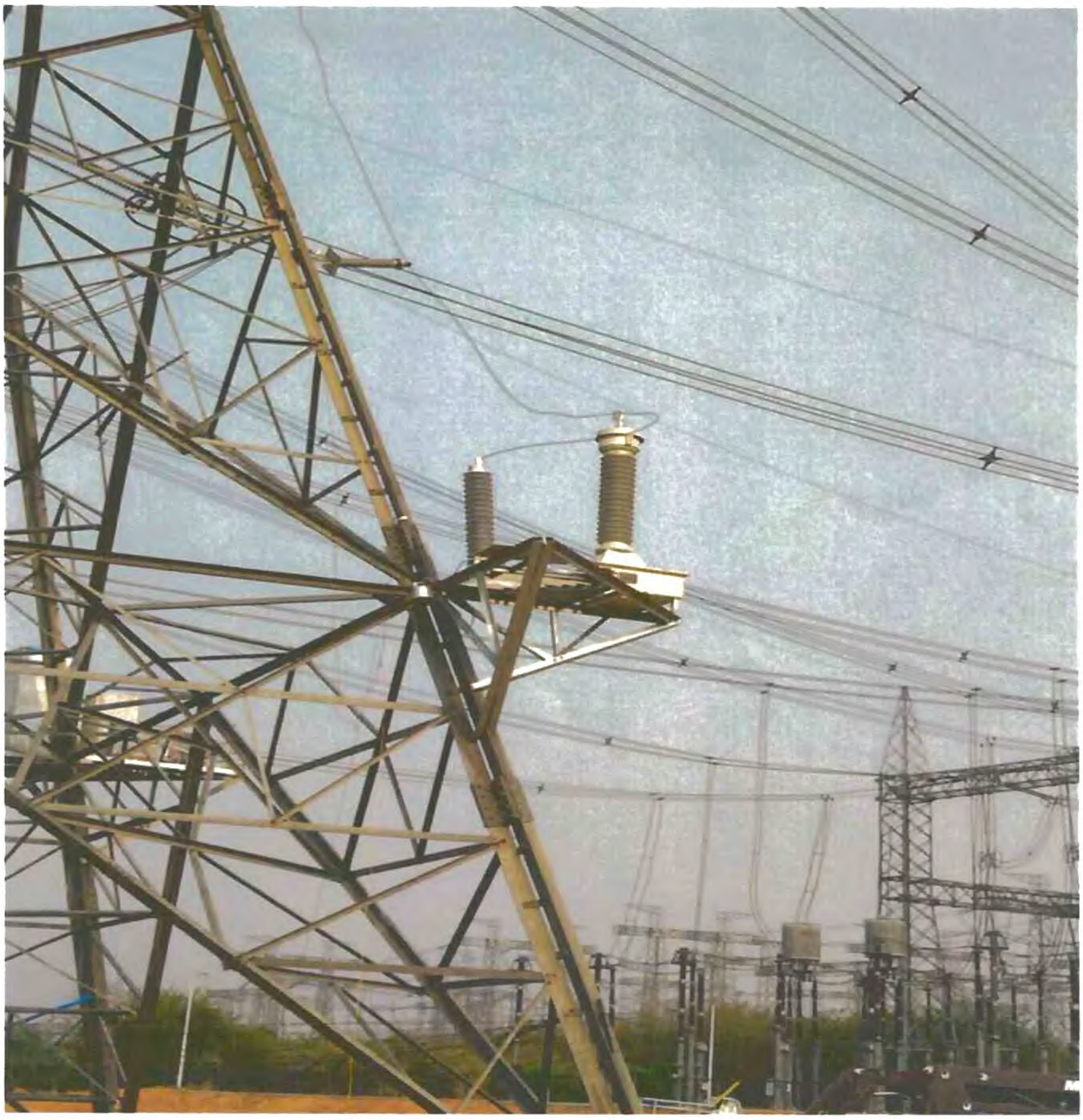
6) **Proposed profit sharing with beneficiary:**

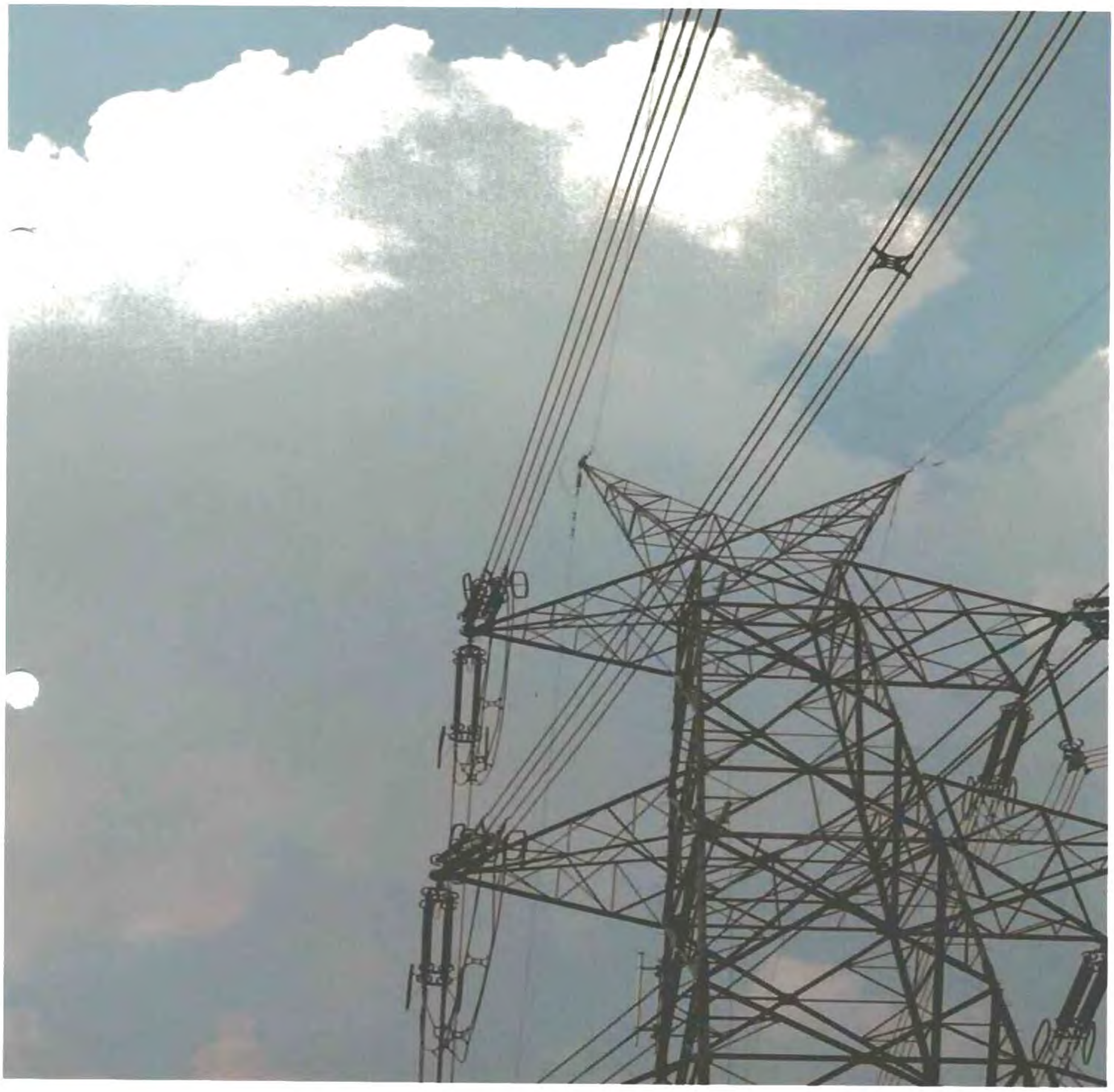
As per CERC Norms in Transmission line business, POWERGRID will get the RoE @ 15.5%, however considering the benefits mentioned above to rural society, POWERGRID is proposing to pay to beneficiary of Rs.12,000/Location/Year (Approx-13.5% of profit before TAX) and accordingly total sharing with beneficiary will be :

Case-I (Leasing of 1250 Towers)	Total Revenue	Rs. 68 Cr/Year
	Total PAT to POWERGRID	Rs. 7.4 Cr/Year
	Sharing with beneficiary :	Rs.1.5Cr/Year
Case-II (Leasing of 6000 Towers	Total Revenue	Rs. 324 Cr/Year
	Total PAT to POWERGRID	Rs.35.6 Cr/Year
	Sharing with beneficiary	Rs.7.2 Cr/Year

Presently all the assumptions are taken based on KPMG Report (estimated values) and interaction with existing Infrastructure service provider. However, the actual revenue /profits will depend upon the cost of procurement for material (supply and installation) and actual revenue earned from the customers. In case of major variations in expenditure and revenue, revised proposal will be submitted to CERC.

Annexure - I





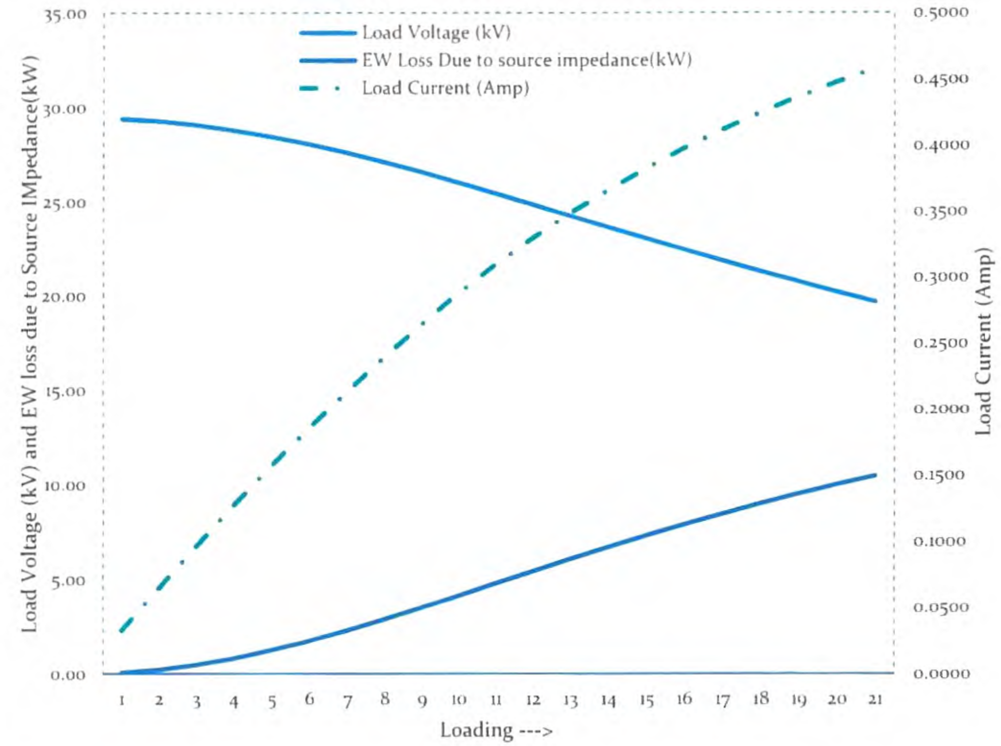
Annexure - II

Simulation Study Results

E/W Voltage (kV)	E/W Current (Amp)	PT Load (kW)	Loss in source impedance (kW)
(0 kV) Short Ckt	0.6100	00	18.605
29.39	0.0326	0.954	0.053
29.27	0.0648	1.892	0.210
29.07	0.0965	2.799	0.466
28.79	0.1275	3.662	0.813
28.45	0.1576	4.470	1.242
28.05	0.1863	5.213	1.735
27.59	0.2139	5.887	2.288
27.10	0.2401	6.488	2.882
26.56	0.2648	7.015	3.506
26.00	0.2880	7.470	4.147
25.43	0.3098	7.855	4.799
24.83	0.3301	8.175	5.448
24.24	0.3490	8.435	6.090
23.64	0.3665	8.639	6.716
23.04	0.3828	8.794	7.327
22.45	0.3979	8.906	7.916
21.87	0.4118	8.978	8.479
21.30	0.4247	9.017	9.019
20.74	0.4365	9.027	9.527

Zs=50 kOhm, Z of E/W is insignificant

GW Load Profile
GW Loss when Shorted =18kW



Induced power drainage can be understood from these studies as well

Annexure - III

Stubbs

Degree awarded with distinction on 30 June 1994.

sertation submitted to the faculty of Engineering University of the srand, Johannesburg, in fulfilment of the requirements for the ' Science in Engineering.

DECLARATION

I declare that this dissertation is my own unaided work.

It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University

____

Signature of Candidate

25th day of March 1994

ACKNOWLEDGEMENTS

The author would like to express his sincere thanks to Mr Rob Stephens, ESKOM Transmission Lines Manager for arranging financial support and to the Technology Research and Investigations Division of ESKOM for their assistance with the measurements. Thanks also to the Johannesburg Sales and Customer Services Department of ESKOM for the construction of the experimental system.

.iving in rural communities often experience frustration when they do not .ıe convenience of mains electricity. Their frustration is worse when there ıigh Voltage transmission line in their vicinity and yet they have no access ıectricity.

. his dissertation looks at the techniques developed by the Research Institute of Hydro Quebec (I.R.E.Q.) in Canada to tap small amounts of power from High Voltage transmission lines using insulated lightning shield wires.

An alternative technique using passive series compensation is proposed as the basis for this research, as it offers the advantages of simplicity and cost effectiveness over the Canadian system which uses active shunt compensation.

An experimental system using series compensation was designed, constructed and tested. The system uses 9.6 km of insulated shield wire on a 400kV transmission line as its source of electric power. The performance of the system is evaluated in terms of its steady state and transient behaviour. The relevant economic factors are also discussed.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Quantity	Symbol
Capacitance	C
Current (electric)	I
Inductance, self	L
Phase difference	ϕ
Potential difference (electric)	V
Power	P
Resistance	R
Impedance	Z

1 INTRODUCTION

1.1 Preview

This dissertation is divided into six chapters which can be summarised as follows:

Chapter 1 Introduction

This chapter describes the need to tap power from high voltage transmission lines in areas remote from existing distribution networks. It proposes that the lightning shield wires of the transmission line can be insulated and used to supply small amounts of electricity to rural people living adjacent to the transmission line.

Chapter 2 Formulation of the Problem

Here the research on this topic carried out by the Institute of Research of Hydro Quebec is reviewed and an alternative solution proposed. The specific aims of this project are also defined.

Chapter 3 Experimental Design

This chapter describes the approach to the design, construction and testing of the experimental shield wire supply system.

Chapter 4 Results and Discussion

The results of the measurements on the experimental circuit are described in this chapter. The behaviour of the system under various steady state and transient conditions is also explained.

Chapter 5 Economic Considerations

This chapter lists the capital costs of the supply system components and suggests how the total cost of the system can be reduced. The maintenance requirements for the system are also described.

Chapter 6 Conclusions

The main conclusions are given and the important considerations are described concerning the technical and economic viability of this type of power supply system. Recommendations for future work are also given in this chapter.

1.2 Background

In countries where there are large, sparsely populated regions, such as in South Africa, there are many small communities that do not enjoy the benefits of mains electricity. This is because the high cost of establishing distribution networks cannot be justified by the small, sparsely distributed loads.

It is particularly frustrating for people living close to high voltage transmission lines when they cannot have access to the electricity. This problem was highlighted when ESKOM had difficulties in 1992 in acquiring a 400 kV line servitude from farmers in the Eastern Cape region who have no electricity.

The Research Institute of Hydro Quebec (I.R.E.Q) in Canada developed a system which could tap small amounts of electric power from high voltage transmission lines. The systems were developed to supply power to seventeen micro-wave repeater stations along the 735 kV line between James Bay and Montreal. These systems use the lightning shield wires which, when insulated from the towers, have a capacitively induced voltage on them. This capacitively induced energy is converted into usable electricity by means of reactive compensation. The other alternatives which were evaluated, but found to be less suitable for this application, were: diesel generators, solar panels and small hydro turbines.

Later BG Checo and I.R.E.Q. developed single phase and three phase systems (SCC2 and SCC3) which use capacitors to couple directly onto HV transmission line conductors to tap small amounts of power.

The purpose of this project is to find a simple and reliable way of tapping power from high voltage transmission lines. The technique of series compensation is proposed as a suitable technique for tapping power from insulated lightning shield wires on these power lines. This technique requires no electronics for voltage regulation as does the Canadian system and is more cost effective.

If a reliable and economical system can be designed to tap small amounts of electricity from HV power lines, there are many benefits which can be realised:

Electrification

The electrification program can be extended to areas where it might not otherwise reach.

Southern African Grid

Direct benefit can be given to communities adjacent to transmission lines in neighbouring countries. This will preserve the good will of these inhabitants and thus curb vandalism and sabotage to the transmission line.

Servitude Acquisition

It may be easier to acquire servitudes from farmers and land owners if they can be offered direct benefit from the transmission line.

2 FORMULATION OF THE PROBLEM

2.1 Review of Previous Work

Most of the work on the concept of tapping power from insulated lightning shield wires on transmission lines has been carried out by "Institut de Recherche" of Hydro Quebec (I.R.E.Q.) and BG Checo International in Canada.

There are two main areas of interest in deriving power from insulated shield wires. Firstly the equivalent source parameters of the insulated lightning shield wires have to be known and secondly a system has to be designed to regulate the output voltage of such a supply.

2.1.1 Lightning Shield wire Equivalent Source Parameters

Before designing a shield wire supply system, it is important to understand the relationship between the physical dimensions of the transmission line conductors and the equivalent source parameters of the insulated section of shield wire. This will enable the designer to optimise the design and later pin-point errors.

There are two papers of relevance in this area. One is based on the research of I.R.E.Q. (Maruvada and Harbec,1978) covering transmission voltages between 300 kV and 750 kV and the other on the research of the Indian Institute of Science (Gururaj and Nandagopal, 1970) covering transmission voltages between 66 kV and 220 kV.

The purpose of Gururaj and Nadagopal's paper, is to give a simplified method for calculating the equivalent circuit parameters for an insulated shield wire (insulated for power tapping) on a transmission line up to 220 kV.

Gururaj and Nandagopal give the general equations relating the potentials on a system of parallel conductors to the charges (per unit length) on the conductors. These quantities are related by the electrostatic coefficients of the conductors which can be derived from the geometrical dimensions of the system of conductors. The relationships are given by the following matrix equations:

$$V(i) = P(i,j) \bullet Q(i)$$

$$Q(i) = P^{-1}(i,j) \bullet V(i,j)$$

where:

$P^{-1}(i,j) = C(i,j)$

$V(i)$:Potential array

$P(i,j)$:Electrostatic coefficient matrix (nxn matrix for n conductors)

$Q(i)$:Charge array

$C(i,j)$:Capacitance matrix

By using the theory where charged conductors are mirrored in the earth plane by conductors with opposite charges, the elements in the electrostatic coefficient matrix can be defined by the following equations:

$$P_{ii} = \frac{1}{2\pi\varepsilon_0} \bullet \ln\left[\frac{S_{ii}}{r_i}\right] \quad [F^{-1}\ m] \qquad \text{(Diagonal Elements)}$$

$$P_{ij} = \frac{1}{2\pi\varepsilon_0} \bullet \ln\left[\frac{S_{ij}}{s_{ij}}\right] \quad [F^{-1}\ m]$$

where:

ε_o	:Permativity constant = $10^{-9} / 36\pi$
P_{ii}	:Self electrostatic coefficient
P_{ij}	:Mutual electrostatic coefficient
S_{ij}	:Distance between conductor i and the image of conductor j
s_{ij}	:Distance between conductor i and conductor j
r_i	:Radius of conductor i

Gururaj uses these equations to derive the Thèvenin equivalent model for a single insulated lightning shield wire for single circuit and double circuit lines. The influences of various geometrical parameters (of the transmission line) on the Thèvenin equivalent model parameters are presented graphically for a range of transmission line configurations (66 kV to 220 kV). A simplified method is given for calculating the induced voltage on the shield wire and the equivalent capacitance (Thèvenin equivalent model), using the graphs presented.

Maruvada and Harbec (1978) explore the possibility of using two shield wires instead of one to tap power from transmission lines. A two-port network equivalent circuit model consisting of two voltage sources and three capacitances is derived which represents the two-shield-wire-source. The equivalent model is used to derive (derivations not shown) the equations for maximum power into a resistive load. The following alternative configurations for shield wire loading are considered:

- one wire loaded with the other isolated,
- one wire loaded with the other earthed,
- both wires loaded independently, and
- both wires connected in parallel to a load.

The purpose of the study was to find the loading configuration which would give the highest power output per unit length of insulated shield wire. It can be shown that maximum power can be tapped if one shield wire is earthed and the other loaded.

Maruvada and Harbec then use a set of matrix equations to derive the network equivalent circuit parameters. A computer program was used to generate a set of graphs (using the matrix equations) relating the equivalent circuit parameters to the physical parameters of a range of transmission line configurations (300 to 750 kV). Similar conclusions to those of Gururaj and Nandagopal were reached concerning these relationships.

The following general conclusions concerning the above relationships are deduced by these two papers:

Induced Voltage

The equivalent open circuit voltage on an insulated lightning shield wire is influenced by the following factors:

- The geometrical position of the insulated shield wire relative to the other shield wire and the phase conductors has the greatest influence. This includes the vertical and horizontal displacements.
- The diameters of the shield wire and phase conductors have little influence on this parameter.

Source Impedance

The source impedance is described and influenced as follows:

- The source impedance is almost purely capacitive.
- The shield wire diameter has the largest influence; increasing capacitance with increasing diameter.
- The relative conductor positions have significant influence.
- The phase conductor diameters have negligible influence.

Source Parameter Derivation Methods

Before designing a power tap-off system it is necessary to determine the equivalent shield wire source parameters for a particular transmission line. A simplified method is presented by Gururaj and Nandagopal (1970) that makes use of graphs to determine the deviations in the equivalent source parameters from a reference case. It is assumed that the relationships are all linear so that the deviations can be summated with the reference case parameters to get the required source parameters. As this method was devised as early as 1970 it may have been useful in times when computing capabilities were not as accessible to designers as they are now. The method described is only suitable for transmission lines in the range 66 kV to 220 kV.

It is now considered more desirable to use standard computer packages for computing these parameters. The **Alternative Transients Program (ATP)** was used in this study.

2.1.2 Voltage Regulating Systems

There are two basic needs to achieve a suitable power supply. Firstly the output voltage should be standard so that standard equipment and appliances can be used. Secondly the output voltage should be relatively constant with varying load magnitudes and phase angles (power factors).

I.R.E.Q. and BG Checo in Canada have done much research in this field. The literature, which consists of papers as well as internal reports, describes a number of systems that have been developed and implemented. The literature describes the use of insulated shield wires as well as directly coupled physical capacitors to tap power from transmission lines. The use of physical capacitors is included in the literature survey as it is electrically similar to the use of insulated shield wires.

Uncompensated supply

Capacitive voltage transformation was used as early as 1971 to derive a power supply (Sturton, 1971). A shunt capacitor divider bank (six 14.4 kV capacitor units, of 2080Ω at 60 Hz, in series; Divider ratio of 6:1) was coupled directly to a 138 kV line and used to supply 75 kW at 13 kV. No reactive compensation was used in this system. This resulted in several problems when a distribution transformer was connected to the capacitor divider:

- **Over voltages and high primary winding excitation currents** due to resonance between the source capacitance and the transformer magnetising impedance, thus causing saturation of the transformer.
- **High fault current** on the secondary side due to resonance of the source capacitance with the transformer leakage inductance.

These problems were partly overcome by increasing the ratings of the transformer and by having suitable protection settings. The voltage regulation, from no-load to 100 kW for load power factors between 0.90 and 0.85 lagging, ranged between 95% and 118% of rated voltage.

Thyristor Controlled Compensation

I.R.E.Q. devised a system to supply 20 kW to microwave repeater stations along the James Bay 735 kV lines using insulated shield wires (Berthiaume & Blais, 1977). Initially no form of reactive compensation was used and the same problems were experienced as described previously. They (Berthiaume & Blais, 1980) later discovered a technique that, by controlling the transformer saturation, could get more power out of the system and could regulate the output voltage to a certain degree (see figure 2.1). The technique used thyristors connected across the windings of the step-down transformer to shunt current across the winding.

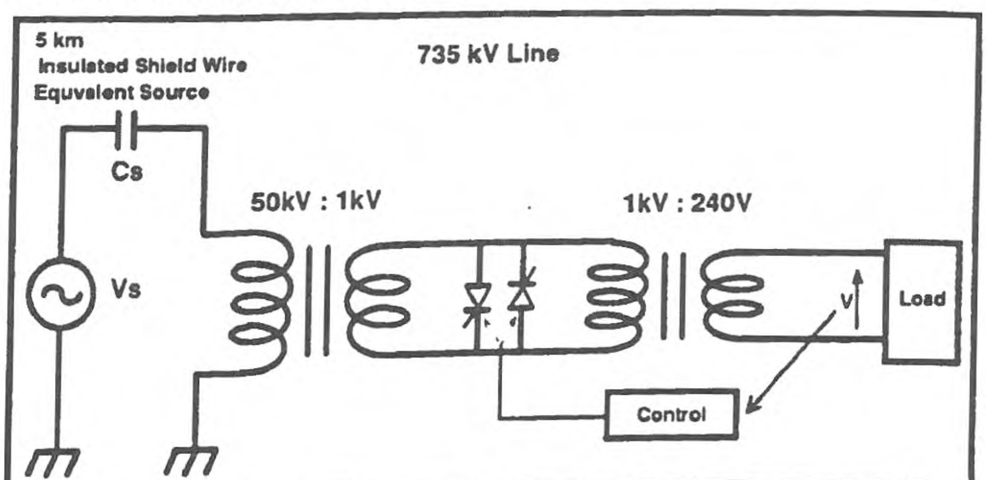


Figure 2.1 Technique developed by I.R.E.Q. to supply 20 kW of power

The best technique, which was later developed by BG Checo and I.R.E.Q. (Ruest and Sybille,1990), used a fixed shunt inductor (reactor) in parallel with a thyristor controlled reactor. By varying the firing angle of the thyristors the degree of compensation could be varied to suit the load conditions (see Figure 2.2).

This technique has more recently been used in single and three phase supply systems using physical coupling capacitors (see table 2.2). The use of physical capacitors is limited to system voltages up to 275 kV.

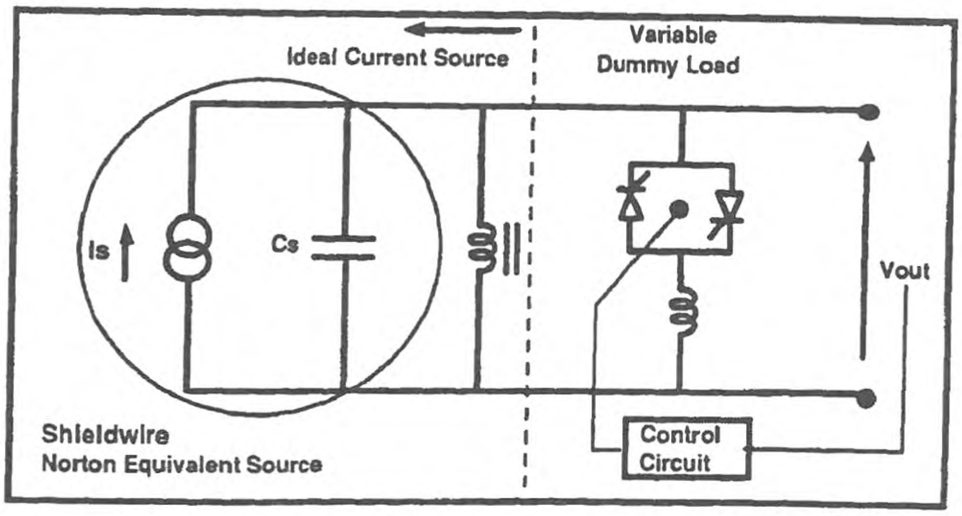


Figure 2.2 Shunt Compensated Source used by the Canadians

The easiest way to understand the operation of this system, is to regard the shield wire source (Norton equivalent model) together with the fixed shunt reactor, as an ideal current source. The thyristor controlled reactor (TCR) can be seen as a variable dummy load which is used to control the output voltage (i.e. TCR fully conducting for no-load condition and open circuit for full load conditions). The system uses a feedback control system to regulate the output voltage.

Advantages:

- A good voltage regulation (±2%)was achieved using this technique.
- No ferro-resonance effects were experienced.

Disadvantages:

- The System is expected to operate in remote and uncontrolled environments where access for maintenance of electronic equipment may be difficult.
- Malfunction of the electronic control circuit causes complete failure of the system.
- Thyristor switching generates harmonics which need to be filtered, thus adding to the cost.
- The cost of the system may be prohibitive. (See Appendix I for Quote)

2.1.3 Examples of Applications

The following table shows some typical applications of capacitive coupling supply systems as described by Ruest and Sybille :

Table 2.1 Typical applications of shield wire supply systems

Place:	Peru, Nahuimpuquio	Venezuela, Isla infierno	Malaysia, Buta Melingtan
HV Line Voltage	220 kV	760 kV	275 kV
System Frequency	60 Hz	60 Hz	50 Hz
Tower Type	Double cct	Single cct	Double cct
Shield wire Voltage	21 kV	62 kV	36 kV
Shield wire length	20 km	3.2 km	40 km
System O/P Voltage	7.2 kV	7.2 kV	6.9 kV
Rated O/P Capacity	70 kVA	35 kVA	100 kVA
Commissioning date	Sep 1982	May 1986	Jun 1987
Application	342 Rural dwellings	Aerial Beacons	450 Rural dwellings

Table 2.2 Applications of physical coupling capacitor (1 phase) supply systems

Place:	Peru, Langui	Peru, (4 systems) Cerro de Pasco -Tingo Maria line
HV Line Voltage	138 kV	138 kV
System Frequency	60 Hz	60 Hz
Tower Type	Single cct	Single cct
System O/P Voltage	13.8 kV	13.8 kV
Rated O/P Capacity	100 kVA	100 kVA
Commissioning date	June 1987	1 in June 1988 3 in Jan 1990
Application	550 households in 4 villages	1600 households in 4 villages

2.2 Proposed Alternative

Series Reactive Compensation

The proposed technique uses a fixed inductive coil (reactor) connected in series with the shield wire source. The value of the inductive impedance is chosen to be equal in magnitude to the source capacitive impedance at power frequency. This gives an output voltage which is independent of load magnitude or power factor at steady state power frequency. This method of voltage regulation relies on the ability to accurately determine the equivalent source parameters, as the reactor has a fixed value and has to be specified up front.

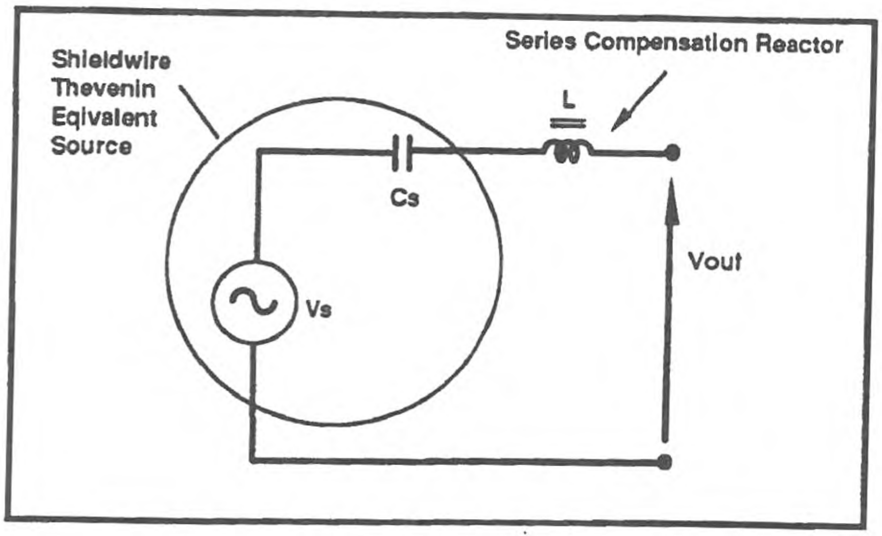


Figure 2.3 Proposed Series Compensated Source

Passive series compensation has the following advantages and disadvantages:

Advantages:

- No need for electronic control of output voltage.
- Fewer components and thus higher reliability.
- Lower cost.

Disadvantages:

- Need accurate values for equivalent source parameters up front.
- Reactor needs to be designed specifically for each system (i.e. no standardisation).
- No control of the system output voltage fluctuations due to transmission line conductor geometry variations such as sag changes

2.3 Specific Aims of this Work

This work focuses on the feasibility of using series compensation to tap power from insulated shield wires on HV transmission lines. To do this it is necessary to look at the important aspects which constitute the performance of this type of power supply.

The proposed technique needs to be evaluated in terms of the following factors:

- **Steady State** performance
- **Transient** performance
- **Protection** requirements
- **Cost**
- Requirements for a **commercial product**

3 EXPERIMENTAL DESIGN

3.1 General Approach

After numerous ATP computer simulations, it was decided that the concept of using series compensation may be a viable technique for shield wire power tapping. The next step was to build and test a proto-type system.

The Kendal Minerva 400 kV line, which was not yet energised, was selected for this experiment. A suitable section of line had to be selected, as well as a suitable tap-off point location, which would allow local access to the test site.

The transmission line profile and geometry were used, by means of computer (ATP) simulations, to find the equivalent source parameters of the insulated section of shield wire. From this, the values of the required components for the compensation system could be designed and a suitable insulation level for the shield wire selected.

The ATP program was also used to establish the transient behaviour of the system under various conditions which enabled the choice of equipment ratings and protection requirements. A protection philosophy was adopted and a relay panel designed and built using standard components. The idea was to use standard components where possible so as to make the system more cost efficient.

Once the proto-type system was built, the protection system was commissioned using primary current injection tests. A test procedure for the whole system was set up and conducted by the Technology Group in ESKOM under the instruction and guidance of the author. The test procedure included tests to establish steady state, transient and protection behaviour under various conditions.

On the basis of the test results, simulation studies were carried out to explain certain behaviours. The necessary modifications were made to the system which was again tested to ensure that the required behaviour had been achieved.

3.2 Site Selection and Transmission Line Data

The Kendal Minerva 400 kV line was used for the proto-type power tap-off system. A 9.6 km section of one shield wire was insulated and a T-off point was made at a site belonging to the Pretoria Parks Board, near ESKOM's Apollo substation. The line was selected as it was not yet energised, which made it easier to retrofit insulators on the shield wire. The section of line between tower 177 and tower 155 was selected with the T-off at tower 177 which afforded easy access.

3.2.1 Transmission Line Profile

The transmission line profile is given in Appendix A. This shows the heights of the conductors at each tower as well as the sag for each span. When using ATP to find the equivalent shield wire source parameters, the "line constants" routine calculates the model for a single span and assumes that the conductor height at both ends is the same. The routine calculates the average conductor heights for the span using the tower connection heights and the mid-span heights in the equation:

$$H_{av} = H_{tower} - \{2/3 \cdot (H_{tower} - H_{mid})\} \qquad [3.1]$$

3.2.2 Line Geometry

The geometries of the towers which are used in the selected span are given in Appendix B

When using ATP for the calculation of the source parameters, a suitable geometry has to be selected which allows one span to represent the whole section of line. The Guyed-V suspension tower (type 520 B) is used 14 out of 23 times for this section of line and was thus chosen as representative.

3.3 Assumptions

The following assumptions were made when choosing a representative span line geometry:

- The tower connection heights and conductor sags could be averaged to get a conductor height which represents the whole section of line according to equation 3.1.
- The most-used tower type can be used as representative, for the tower-top geometry.

3.4 Computer Simulations

The simulations for this study were carried out on the Apollo Domain 4000 work station using the Alternative Transients Program (ATP). The two main purposes for the simulations were, firstly to establish the equivalent shield wire source parameters which could be used as the basis for the design of the supply system, and secondly to determine the steady state and transient behaviour of the system.

3.4.1 Derivation of Source Parameters

The "Line Constants" support routine (see Appendix C for data input file) was used to derive a "Distributed Parameter" line model based on the assumptions made concerning the line's physical geometry. The model was then used in the ATP main program (see Appendix C for program listing) to establish the source parameters.

Induced Voltage

A 420 kV source was applied to one end of the transmission line under steady state conditions. The steady state voltage on the insulated shield wire could then be directly determined from the steady state output of the ATP program. This was found to be **47.5 kV** for the test case.

Source Impedance

The source impedance was found by short circuiting the insulated shield wire at one end and determining the short circuit current. This was found to be **104 nF** for the test case [1].

3.4.2 Steady State Design

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[1] **Important Note:** After measurements, it was found that these simulated results were not accurate. The reasons for this are discussed later in the relevant section. The design hereafter however, still assumes that these simulated source parameters are correct. The discrepancy, as far as the actual construction and testing is concerned, is accommodated and described in Chapter 4.

Once the source parameters had been calculated, the system could be designed to give a standard output voltage with the required compensation. To get a standard voltage, a physical capacitor is connected from the insulated shield wire to ground, giving capacitive voltage division. The equivalent source then becomes the required standard voltage with a new series capacitance equal to the sum of the two capacitances (shield wire source + physical capacitance). The combined capacitance now needs to be compensated using a suitable fixed inductance.

For the test case, a 47.5 kV induced voltage could be transformed to 22 kV using a physical capacitor of 124 nF. This gives an effective source capacitance of 224 nF. To compensate for this impedance at 50 Hz, a reactor of 45.2 H is required. An X:R ratio of 50:1 (at 50 Hz) was assumed, which gives the reactor an internal resistance of 284 Ω. These values were used as the basic model in ATP for further simulation studies.

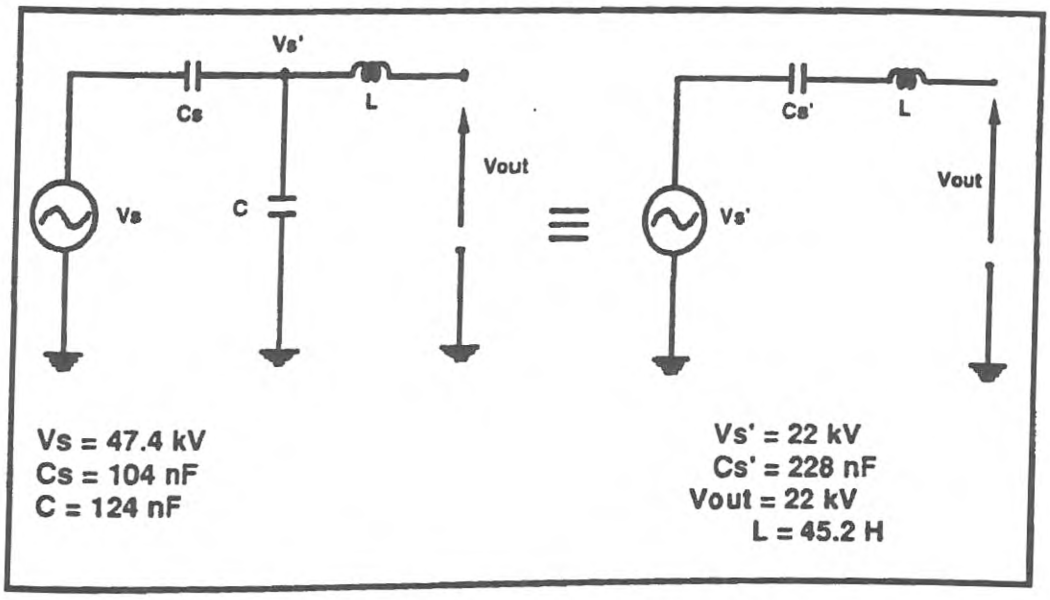

Figure 3.1 Diagram Showing Steady State Design Values

There are two important considerations for steady state performance. Firstly the output voltage regulation when the system is loaded to full rated output and secondly, the behaviour of the shield wire voltage when the system is loaded. The latter is needed for determining the insulation level required on the shield wire.

If the system is loaded up to 50 kVA the output voltage drops from 22 kV to 21.3 kV, assuming a unity power factor load. This gives a voltage regulation of 3%.

With a 50 kW load (power factor = 1),with a constant load voltage of 22 kV, the shield wire voltage increases to 39.8 kV from an unloaded voltage of 22 kV. The shield wire voltage increases even further if the load is inductive (power factor < 1 lag). At worst, the shield wire voltage increases to 54.4 kV for a purely inductive 50 kVAr load. This is however, very unlikely in practice.

3.4.3 Transient Performance Design Considerations

This section describes the simulations carried out to establish the type of behaviour to be expected under various transient conditions. The two main areas of importance are the switching and fault condition behaviours.

Switching

An electrical supply system needs to be switched ON and OFF, for both operating and protection purposes. Normally this is not a problem, but as this circuit has relatively large energy storage capacity, the switching of the circuit requires careful consideration.

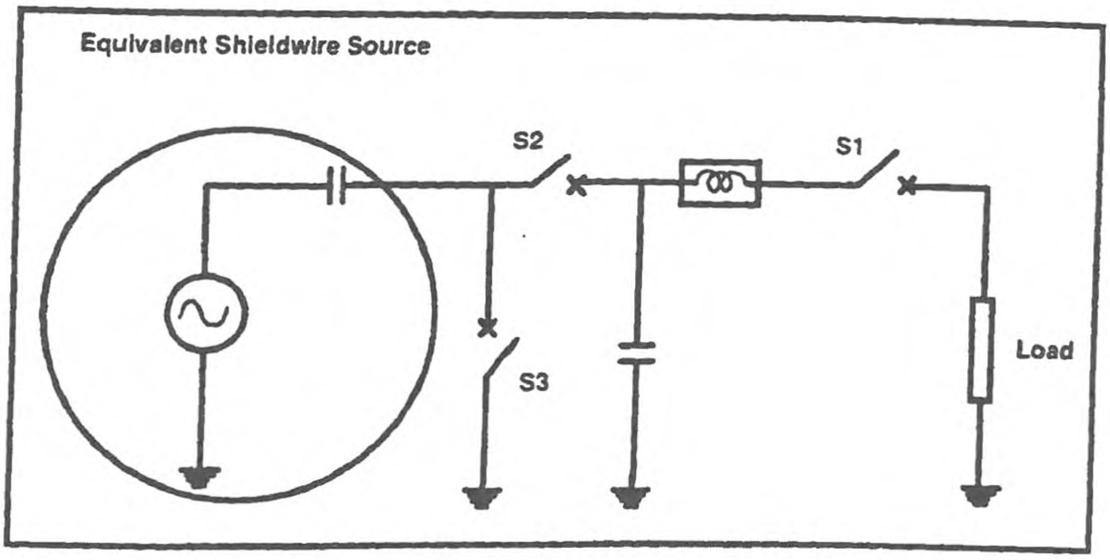

Figure 3.2 Diagram Showing Alternative Switching Positions

Series switching is the most common form of breaking an electrical circuit. However, in this type of circuit, series switching results in trapped charge being left on the total source capacitance during de-energisation (see figures D1 to D6). A DC voltage equal to the peak voltage during "ON" conditions is trapped on the capacitance. This assumes that the current feeding the source will be interrupted at current zero (which is reasonable considering the high series inductance of the circuit). The voltage at the instant of current zero is at its peak, due to the 90° phase displacement between the current through, and the voltage across a capacitor. The result is that a high recovery voltage (up to 100 kV peak, as per figure D3) is experienced by the circuit breaker. This problem exists for switching at the output node and at the shield wire node and is particularly significant when trying to clear a fault.

Shunt switching for de-energising the system (closing S3, with S1 and S2 closed in figure 3.2) gives the best performance (see figures D7 & D8). If the shield wire is switched to ground to turn the system OFF, there are no undesirable effects. The steady state current, which flows when the shield wire is earthed, is limited by the high source impedance. A relatively high transient current flows when the physical capacitor is short circuited. This depends on the stray inductance in the loop formed by the earthing conductor and shunt capacitor.

For energising the system however (opening S3, with S1 and S2 closed in figure 3.2), shunt switching may cause a problem, as there will always be a DC charge on the source capacitance when the earth switch is opened, which must discharge somewhere. This is because the voltage across the capacitance is its peak when the current is interrupted at its zero crossing. It was decided that, despite this potential problem, this technique is the most suitable. It was assumed that the DC charge would discharge through the load with little undesirable effects[2].

Fault Conditions

The most onerous condition which the system can be subjected to, is a short circuit on the output. This causes the voltage on the shield wire to climb until the shield wire insulation breaks down (see figure D9). This is due to the high Q-factor of the circuit which, in such conditions, is close to perfect resonance and has nearly no damping (a voltage source is being short circuited by a series resonant branch).

There are three ways (see Figure 3.3) in which the shield wire voltage can be prevented from uncontrollably tending toward infinity:

- Firstly, **spark gaps** are used on the insulator discs, used to insulate the shield wire, which flashover at a predesigned voltage (70 kV rms.). These automatically prevent the shield wire voltage from exceeding this value.
- Secondly, if a suitable **surge arrester** (Gapless Metal Oxide) is used between the shield wire and ground, the voltage can be effectively clamped at the knee-point voltage of the arrester (see figure D10). This happens because, as the voltage on the shield wire increases, the arrester conducts more current and thus introduces more damping into the resonant circuit. It is however important to ensure that the fault condition is cleared before the maximum energy rating of the surge arrester is reached. It is also desirable that the surge arrester should clamp the shield wire voltage at a value below that of the spark-gap flashover voltage[3].
- The last technique, is to design the **saturation** voltage of the reactor to be just above its rated voltage. This causes the resonant circuit to go out of tune when the fault current exceeds the rated full load current of the reactor and thus limits the voltage that develops in the circuit. If this is used in conjunction with the surge arrester, the energy dissipated in the arrester can be significantly reduced, which means that a fault can be tolerated for longer (compare figures D13 and D14).

These three mechanisms were simulated to demonstrate the effect and can be seen in Appendix D. All three mechanisms were employed in the design of the system and formed an integral part of selecting the insulation levels and voltage and current ratings.

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[2] This assumption turned out to be false. See Chapter 4 section 4.2.1

[3] In reality, the flashover voltage of the spark-gaps and the knee-point voltage of the arrester in the proto-type were very close together. This caused the spark-gaps to flashover before the arrester could clamp the voltage as can be seen on the measurements in Appendix E

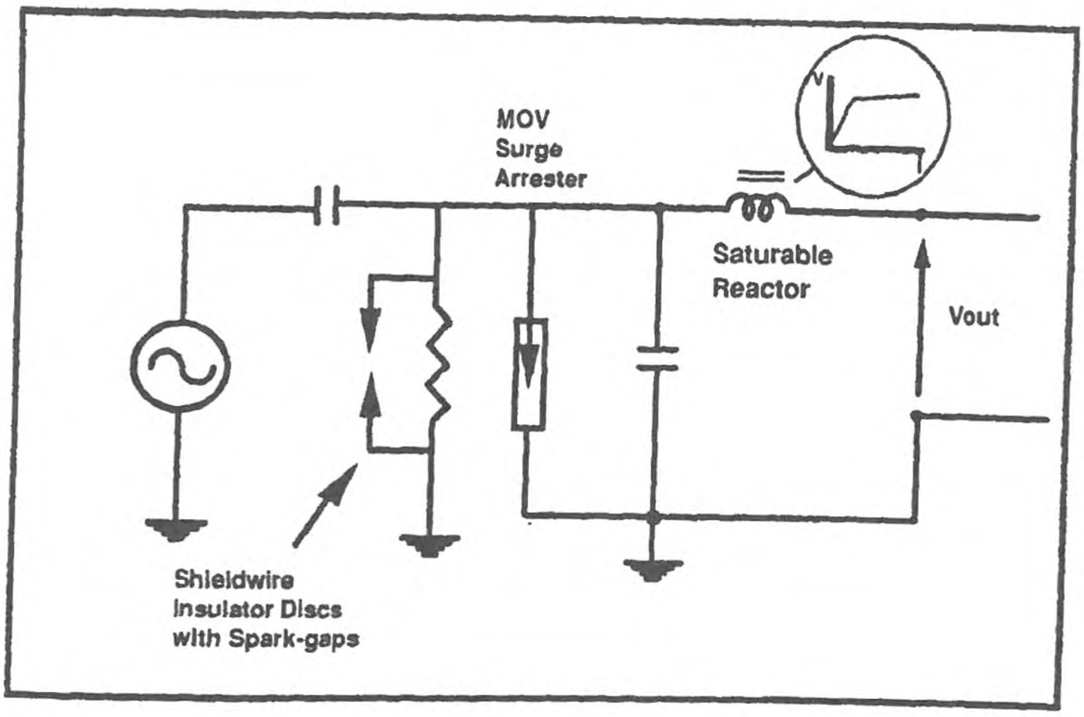

Figure 3.3 Diagram Showing Voltage Limiting Mechanisms

3.5 Proto-Type Design and Construction

On the basis of the ATP simulation results, the specifications for the individual components could be derived. The specifications for the components are given in Appendix F, but the design approach is given in the following sections.

.5.1 Component Sizes and Ratings

The values of the electrical components are determined starting from the equivalent source parameters as derived from the ATP simulation. The current and voltage ratings are determined by considering what load will be supplied and how the system will behave under transient conditions as described earlier.

Shunt Capacitor

The required output voltage determines what value of shunt capacitance is required. It was decided to make provision for possible errors in the assumed source parameters by having the option of changing the shunt capacitance value.

For the Shunt capacitance value it was assumed that the source capacitance would be correct, but that the induced voltage may be higher or lower than calculated[4]. Three values of capacitance (63 nF, 110 nF, 150 nF) were chosen which would give a system output voltage of 22 kV ± 2 kV for an induced source voltage ranging from 33 kV up to 60 kV, assuming a source capacitance of 104 nF. The values of capacitance were chosen such that all

4 This assumption proved to be false and in fact the opposite was true. The problem is described in section 4.1.1

three could be obtained by series or parallel combinations of four discrete capacitors housed in two capacitor cans (see Specification in appendix F).

The Voltage rating was chosen by considering the full load (power factor = 1) condition and the short circuit condition of the system. As described earlier, the voltage on the shield wire (and consequently across the shunt capacitor) increases for increasing load current. The full load condition causes a voltage of 39.8 kV to appear across the capacitor. The surge arrester clamps the voltage to 70 kV rms. under fault conditions as described earlier.

These conditions translate to having a continuous voltage rating of at least 40 kV and a short time rating of 70 kV. In practice, capacitors with a continuous rating of 50 kV were available and were used. This was achieved by using two capacitor cans (25 kV each) in series, mounted on an insulator pedestal.

Series Compensation Reactor

The reactor is an iron cored, paper-oil insulated design. The input side bushing has an oil conservator and the whole unit is hermetically sealed.

For the Inductance value it was accepted that 100 % compensation would probably not be attainable due to uncertainties in assumptions and calculations as well as manufacturing tolerances. This means that the net source impedance of the system might have been slightly inductive or capacitive, but was assumed would be insignificant. An inductance of 45 H ± 4% [5] was specified based on the equation for series resonance:

$$2\pi fL = \frac{1}{2\pi fC} \qquad [3.2]$$

A typical X:R ratio for iron cored reactors is 50 which gives the reactor an expected internal resistance value of 283Ω at 70°C.

The current rating was specified at 2.3 A for continuous operation which would give the system an output capacity of 50 kVA assuming an output voltage of 21.7 kV at full load. A short time (5 min) overload current of 5 A was specified to take account of potential fault conditions.

The voltage rating was specified based on the full load current rating in conjunction with the impedance value.

The saturation knee-point was desired at ±1.2 p.u. of the continuous rated current. This was to give the characteristic of de-tuning the resonant circuit during fault conditions as described earlier.

Switch Gear

The switch gear for the system consists of a pole-mounted earthing switch (S3 in figure 3.2) and a manually operated isolator (S2 in figure 3.2). Both switches are based on standard outdoor 22 kV switches, modified to give 44 kV insulation levels. The earthing switch is used to energise and de-energise the system and is activated using a pneumatic actuator (see Specification in Appendix F). The isolator is manually operated using a "link stick". The

5 This tolerance on its own has only a slight influence on the steady state output voltage regulation.

switch gear was mounted at the top of a 10 m high wood pole which formed the interface between the shield wire tap-off point and the supply system.

The switching speed is what dictated what type of actuation was needed for the earthing switch. It was decided that a pneumatic actuator driven by a pressurised gas bottle and solenoid valves would be suitable for this application. The closing time (time to de-energise) was specified at 0.5 seconds from the time the signal is sent. This is slow compared to other more expensive types of circuit breakers, but was considered adequate for this application, remembering that a fault can be tolerated for a short time.

The total opening time is not critical as the system is energised by opening the switch. A capacitive current of 1.5 Amps is to be interrupted during opening, which was assumed would be achieved by using a standard spring steel arcing contact which whip-lashes open.

Current Transformers (CTs)

Due to the low current rating of the system, wound primary, class-X CTs were required. The CTs are required to measure the current flowing into the reactor and in the earthed return path. This allows over current and earth fault conditions to be detected. A turns ratio of 1 : 2.3 was specified with a maximum continuous primary current rating of 2.3 A. The other details of the CT ratings are given in Appendix F.

Distribution Transformers

Three standard 22 kV : 230 V, 16 kVA distribution transformers were used. The transformers have 3 secondary tappings to give 95%, 100% and 105% turns ratios.

Transient Damping Filter

After it was discovered that the system needed a certain amount of damping for load switching and energising purposes, a filter was designed to dissipate any transient energy which may appear in the circuit. The type of filter is shown in figure 4.3.

It was decided that a low voltage filter would be more cost effective than a high voltage one, considering the cost of insulation. The problem was first to choose what reactive component values to use, remembering that during steady state conditions the parallel resonant combination of capacitor and inductor would carry the full rated current continuously. It boils down to the question of :"How much energy needs to be stored in these elements?" The lower the inductance (and capacitive impedance) the higher the energy rating of the reactive components. It was found through ATP simulations that better damping of the transient oscillations could be obtained using component values giving higher energy storage capacity. Higher energy storage capacity, however, costs more. The trade-off is cost versus performance and components were chosen as small (energy storage) as possible and still giving satisfactory performance. This was found by iteration using ATP and consulting the manufacturer as to what was physically possible. The specification can be seen in Appendix F.

The resister was the next element to be specified. This component determines how quickly transient oscillations are damped. It was found during ATP simulations that only a restricted range of resistor values could be used to get satisfactory damping characteristics. Optimum transient damping was found by iteration and is given by a resistance of between 2.5 Ω and 10 Ω for this particular circuit.

3.5.2 Insulation Co-ordination

There are two main sources of voltage stress which could damage the system components. The first voltage stress occurs when there is a short circuit on the output of the system as described earlier. The second source of over voltage is when lightning strikes the shield wire directly. The system components must be designed to be able to withstand these potential voltage stresses.

Table 3.1 shows what values were used for the 50 Hz withstand and lightning impulse withstand voltages for the various components. The actual ratings are the result of what was available in practice and not always the specified value. The insulation levels were selected based on the following assumptions:

- The maximum 50 Hz voltage on the shield wire occurs during a short circuit on the output of the system and is limited to 70 kV (rms) by the surge arrester, or the shield wire spark gaps.
- Full load conditions would not cause the shield wire voltage to exceed 44 kV rms.
- An external flash over between the insulated shield wire and ground (tower) is considered not serious as the fault current in such a case is limited by the high source impedance. The insulation is restored once the fault is cleared.
- The 50 Hz wet withstand voltage is the limiting criterion for external insulation.

Table 3.1 **Actual Insulation levels (to ground) of system components**

Component Name	Suspension Insulator (long-rod)	Strain Insulator (3 Discs)[6]	Switch gear	Capacitor	Reactor Source side[7]	Reactor Winding	Reactor Load side.
50 Hz Wet Withstand Voltage (kV rms)	50	70	70	95	95	95	95
Lightning Impulse Withstand (kV Peak)	190	100	170	250	250	300	200

The table shows that the external insulation levels of equipment on the source side of the shield wire are lower than the insulation levels of the capacitor and the reactor. From this it is assumed that in the event of

6 These insulation withstand voltages are determined by the spark-gap settings of the insulator discs.

7 This includes the insulation levels of the Current Transformer on this side of the reactor.

excessive voltage stress, the external insulation of the shield wire will break down before the internal insulation of any of the main components. As suggested, this is considered not serious, as a break down across the external insulation does not cause permanent damage. Permanent damage would result if the internal insulation of either the capacitor, CTs or reactor was to break down.

A surge arrester is placed in the circuit at the input node. The surge arrester has a rated voltage of 60 kV, a one second temporary over voltage rating of 70 kV and a maximum discharge voltage of 195 kV (peak) for a 20 kA current impulse (8/20 μs).

3.5.3 Protection Requirements

There were five basic protection requirements which were considered important. A protection relay panel was designed (see Appendix F), based on a 12 V D.C. battery supply, using electro-mechanical relays and housed in a steel cabinet. The 12 V battery is charged by means of a standard trickle charger from the output of the system. The basic functions of the protection panel are described in the following sections.

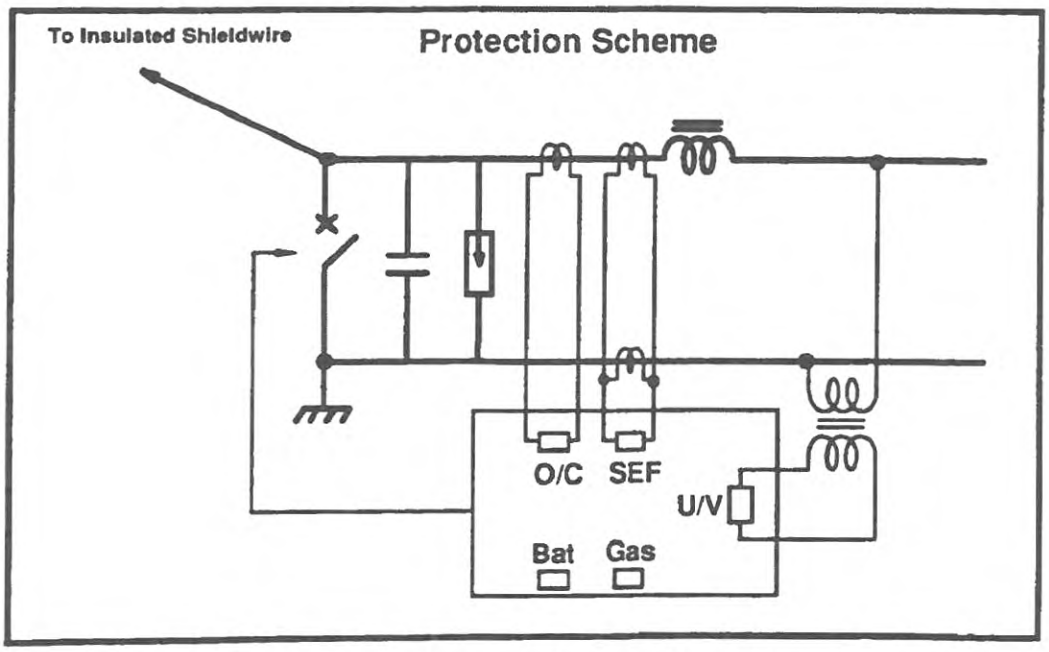

Figure 3.4 Schematic Diagram of Protection Scheme

Over Current (O/C)

The supply current is measured by means of a CT positioned on the source side of the reactor. The secondary of the CT drives an instantaneous relay which was set at 2.5 A and causes the system to trip if the reactor current exceeds this value. This function protects the system in the case of short circuits on the output of the system.

Sensitive Earth Fault (SEF)

If a high resistance fault occurs between the live output conductor and earth somewhere on the distribution side of the system, the over current relay may not detect the fault. It is thus necessary to have a means of discriminating between small loads and high resistance earth faults.

This can be done by measuring the current flowing into the reactor and the current returning from the load via the earthed return (neutral) conductor. The difference between these two currents is the earth fault current. This way the earth fault relay can be set more sensitively (300 mA) than the over current relay.

Under Voltage (U/V)

If the insulated shield wire is struck by lightning, the spark-gaps on the strain insulator assemblies (on the shield wire) will flash over at 100 kV peak. There is the possibility that the 50 Hz induced voltage will sustain the arcs in these gaps after the lightning stroke has passed. This would render the system inactive, until the arcs were extinguished by some means. It was decided that this situation should be controlled, so that the system could not be left inactive for an indefinite period during such conditions.

A relay is used to detect the output voltage (via the secondary of the distribution transformer) of the system. If the voltage drops below a pre-set value (200 V), the relay causes the system to trip by earthing the shield wire. If the under voltage is as a result of a spark-gap flash over, the arcs will automatically be extinguish when the earth switch is closed. The relay re-opens the earth switch after a certain time (10 seconds) and thus re-energises the system.

The under voltage relay is only re-enabled if the output voltage of the system is restored after the close-open sequence. This is necessary to prevent the relay from operating continuously in the event that the **transmission line** is switched out for any reason.

Low Battery Voltage

A relay is included to monitor the protection battery voltage level, so that if the battery becomes faulty, the system will trip and can only be reset once the problem is rectified.

Low Gas Pressure

Similarly, the pressure in the gas bottle used to drive the switch is monitored. If the pressure drops below a certain value, the system trips and can only be reset once the gas bottle is replaced or refilled.

These last two requirements are to ensure that the protection system does not fail without being noticed. The system cannot afford to be without a protection system in the event of a short circuit on the output of the system (see section 4.3.3).

3.5.4 Construction

The construction of the system was based on ESKOM's substation design standards. All equipment is enclosed in a fenced yard and heavy equipment is mounted on steel support structures. The switch gear is mounted at the top of a 10 m high wood pole which is where the tap-off point conductor joins the system to the insulated shield wire. The capacitor is mounted on a bracket on the side of the wood pole (see photograph in Appendix G). The protection relay panel was housed in a steel cabinet inside a port-a-camp building.

3.5.5 Earthing

ESKOM standards were used to design the system earth mat which was then connected to the adjacent transmission line tower. This connection gives a better earth return path (<2Ω) for the tap-off supply system.

3.6 Proto-Type Testing

The Technology Research and Investigations department in ESKOM was requested to do the measurements of the system behaviour during the commissioning phase of the project under the instruction and guidance of the author. The mobile transient measuring facility was used for this purpose. The equipment used for the measurements is described in Appendix H.

The Nicolet System 500 formed the basis of the measurement system with fibre-optic coupling to the voltage dividers and current transformers.

3.6.1 Aims of Measurements

The main aim of the measurements was to determine the behaviour of this type of supply system under steady state and transient conditions. From this, it could be decided what modifications were necessary and where there were errors in the assumptions made during the design of the system. It was also necessary to see whether the protection system operated as designed and if the protection philosophy used was adequate for this type of supply system.

3.6.2 Protection Commissioning and Testing

The over current and earth fault protection relay settings were made by injecting known currents on the primary side of the current transformers. This was done before the system was energised. The other protection settings were also tested before the system was energised.

The protection was also tested when the system had been energised. A short circuit was applied to the output (primary side of transformers) of the system and the time to clear the fault was measured.

To check that the sensitive earth fault protection worked, an unbalanced condition was artificially created by short circuiting one of the CT secondary windings and disconnecting it from the protection panel. A load was gradually increased, by means of a variac, until the system tripped.

3.6.3 Steady State Performance

Source Parameters

The first step was to determine the actual equivalent source parameters. The **induced voltage** on the shield wire was measured using a Haefely High Voltage RC divider (3 stacked elements). The shield wire was then short circuited to earth and the short circuit current measured using a Pearson current transformer. From these two values the **source impedance** could then be determined.

The physical capacitor was then connected to the shield wire and the resulting voltage measured. This reduced voltage and the known capacitance could then be used to verify the previous two measurements.

At this point, a capacitor value was chosen (from the three design options) to give a suitable output voltage as well as an effective source impedance similar in magnitude to that of the reactor. It is important to have the circuit as closely tuned as possible.

Voltage Regulation

Once the system was energised, the load on the secondary side of the transformers could then be increased to see what the primary and secondary voltage regulation was. The intention was to increase the resistive load from zero up to 50 kW, but for reasons described later, this was not possible. A load of 17 kW was achievable with the equipment available.

Non-linear Load Response

The system was also tested to see how it responds to harmonic generating loads. A single phase-to-three phase converter was used to drive a 3 Ø induction motor which was loaded using a DC generator and a 7.5 kW resistive load.

3.6.4 Transient Performance

System Energisation

Once the correct capacitor value was selected, the system was energised by opening the earth switch. The distribution transformers were already connected to the supply, but with no load on the secondary side. For reasons discussed later [8], the system had to be energised with a resistive load connected on the secondary side of the transformers. The behaviour of the system during energisation was later explained and ATP simulations used to enable us to make the necessary modifications to the system.

Load Rejection

The system was also monitored during load rejection events. It was necessary to see what happens to the stored energy in the reactive elements when a large load is switched off. This is particularly important when there is no load left on the system after load rejection.

During all measurements, a 40 W fluorescent light was illuminated through the supply. From this, a visual perception of the light "flicker" could be gained during load switching.

Fault Response

The system's behaviour during fault conditions was also measured. A short circuit was applied to the output of the system while the shield wire voltage was monitored. The speed of the protection system was also noted.

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8 See section 4.2.1 in the chapter on Results

4 RESULTS AND DISCUSSION

4.1 Steady State Performance

The steady state output voltage was a perfect 50 Hz sinusoidal wave when the system was not loaded. The supply current was also a 50 Hz sinusoid when the system was loaded with a linear load (see Figure E3).

4.1.1 Source Parameters and System Output Voltage

The system was originally designed to operate from 10 km of insulated shield wire. In practice it was found that only 9.6 km could be insulated, as one end span crossed over another transmission line which was not allowed to be switched out due to contingency reasons.

Source Parameters

The measurements showed the induced voltage to be 45.1 kV rms, compared to the calculated value of 47.4 kV.

The short circuit current of the shield wire was found to be 807 mA rms which gives a source impedance of 57 nF, compared to the anticipated value of 104 nF (see section 4.4 for explanations).

System Output Voltage

Due to the higher shield wire source impedance, the output voltage had to be reduced so that the total (including the physical capacitor) capacitive source impedance (magnitude) could still be close to that of the reactor.

This was achieved by connecting the capacitor to give 150 nF (one of the three designed values). This reduced the output voltage to 12.4 kV, but still allowed the capacitive and inductive impedances to be closely matched at 50 Hz.

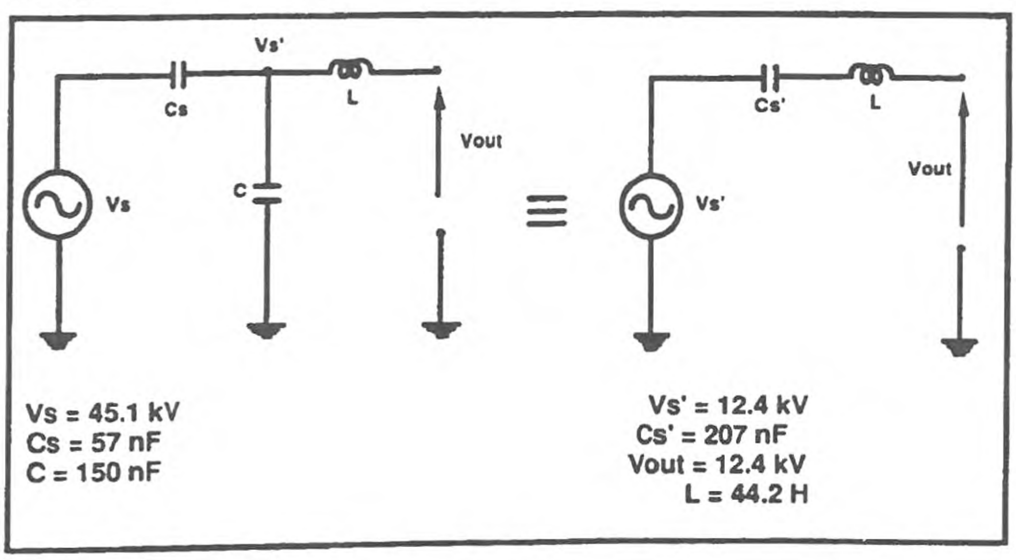


Figure 4.1 Diagram Showing Actual System Values After Modification

Three 22 kV : 230 V distribution transformers were already erected and thus had to be used. Due to the lower system output voltage (12 kV), only 120 V could be obtained from each secondary winding. The 50 kW resistive load bank (12 resistive elements of 12.7Ω each) was also constructed assuming a secondary output voltage of 230 V. With the output voltage being half of what it should have been, only one quarter of the power (12 kW) could be drawn from the system using the same resistor bank.

In order that some standard appliances might be tested, and that more power could be drawn from the system, certain modifications were made (see figure 4.2). The secondary windings of two transformers were connected in series to give a combined output voltage of 240 V. This way the two combined transformers could be used to draw 16 kW and the single transformer used to draw 4 kW from the supply, giving a total of 20 kW. This was considered enough to get an idea of the system's output voltage regulation.

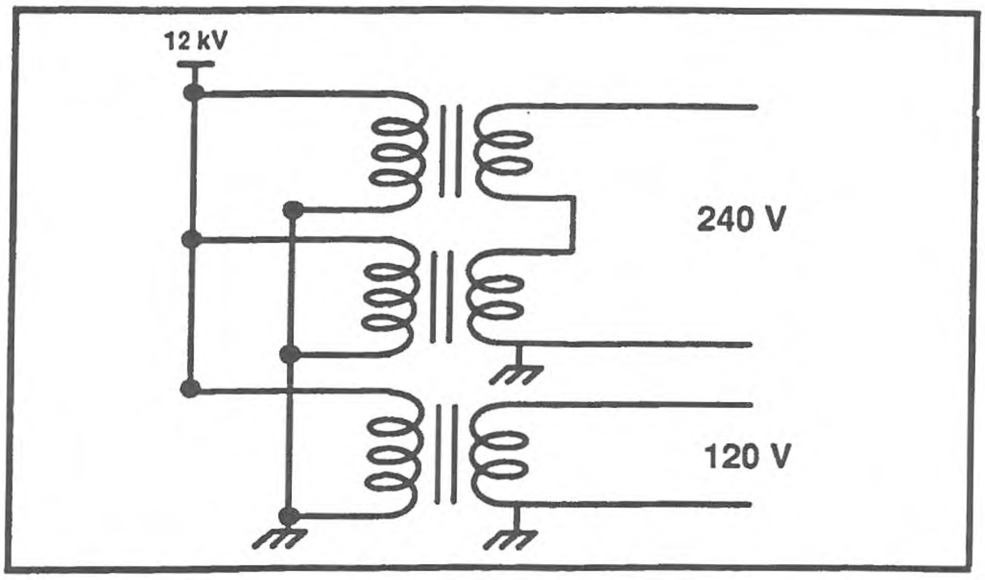


Figure 4.2 Modified Distribution Transformer Secodary Connections.

4.1.2 Voltage Regulation

The results of the voltage regulation tests are given in tables E1 & E2 in Appendix E. The primary output voltage dropped by 1.3% when the system was loaded to 17 kVA. This value can be extrapolated for higher load demands and is considered very satisfactory.

The secondary voltage regulation of a single distribution transformer is close to 3% when fully loaded, which is considered acceptable in practice.

4.1.3 Non-Linear Load Response

When the system was loaded with a non-linear load (1∅ to 3∅ converter, 7.5 kW), the output voltage was distorted almost into a square wave shape (see Figure E 8). This can be explained as follows:

The non linear load generates a large percentage of harmonic currents. The source has a high impedance at frequencies other than the series resonant frequency, so the harmonic currents cause the output voltage to distort significantly. The harmonic voltage distortion at the nth harmonic V_n, can be given by the following formula:

$$V_n = I_n \times Z_n$$

where: I_n is the nth harmonic current generated by the load.

Z_n is the impedance seen by the nth harmonic current.

Although the significantly high capacitive source impedance and inductive compensation impedance cancel each other out at 50 Hz, this is not the case at other frequencies.

4.2 Transient Performance

The system's transient responses to energising and load switching are more interesting and revealing about the nature of the circuit.

4.2.1 System Energisation

Problem

When the system was energised with no load connected on the secondary of the transformers, the over current protection relay immediately caused the system to trip. If, however, the system was energised with a resistive load connected on the secondary side, the system had no problem energising.

Explanation

This can be explained as follows. When the earthing switch is opened, the source short circuit current (capacitive) is interrupted at the zero crossing. At this instant the voltage across the source capacitance is at its peak and is trapped as a DC charge. This DC charge has to discharge somewhere in the circuit. If the transformers are connected, but with no load, the trapped charge finds its way through the magnetising impedance of the transformers as a transient current with a high DC component. This transient excites a ferro-resonance phenomenon, due to saturation of the transformer cores where high currents (up to 4 Amp peak) and voltages (as much as 100 kV peak across the transformer) oscillate between the energy storage elements in the circuit with little damping (see figure E2 and E9). The over current relay was set to trip instantaneously at 2.5 Amp RMS, which explains why the system would keep tripping on energisation

When a load was connected, there was an alternative path for the trapped DC charge to discharge through. There was also significant damping in the circuit which suppressed any transient oscillations.

Solution

Initially a resistive load was used to damp out the energising transient oscillation (see Figure E3). This was however not considered to be a good permanent solution, as energy would be wasted during steady state ON conditions. After the behaviour of numerous filter configurations was simulated, it was decided that a low voltage parallel resonant filter was the best solution. The filter consists of a capacitor and inductor in parallel with a resistor in series (see figure 4.3). If an non 50 Hz (transient) voltage appears across the filter, a transient current flows through the resistor and thus dissipates the initial energy stored in the circuit (see Figures E4 & E5).

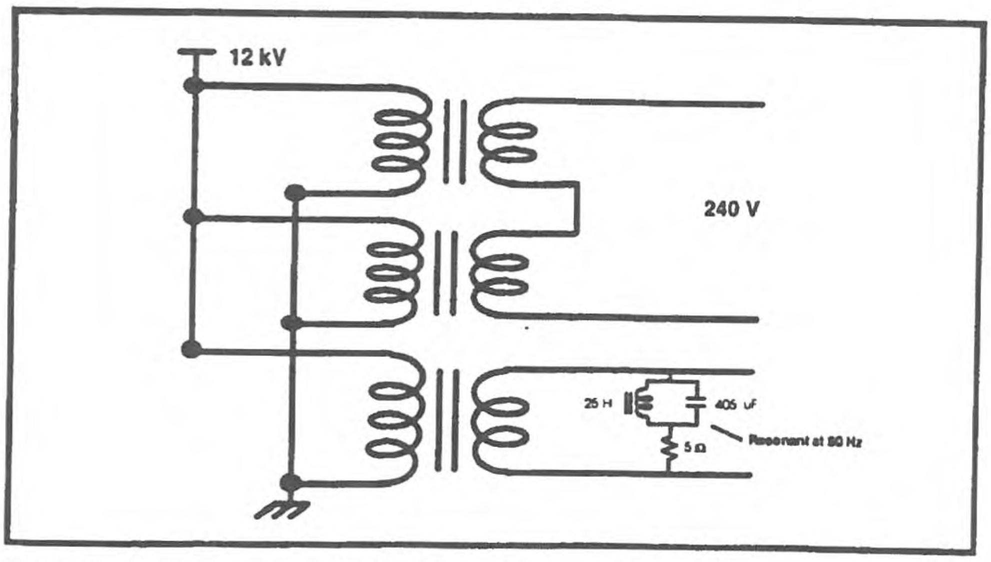


Figure 4.3 Application of Low Voltage Parallel Resonant Filter.

4.2.2 Load Rejection

Problem

Load rejection also resulted in some interesting behaviour (see figures E9 & E10). The characteristic behaviour of the system when switching off a load (leaving the system unloaded) is similar to that of system energisation. This also resulted in the system tripping on over current protection when a significant load was completely removed from the system.

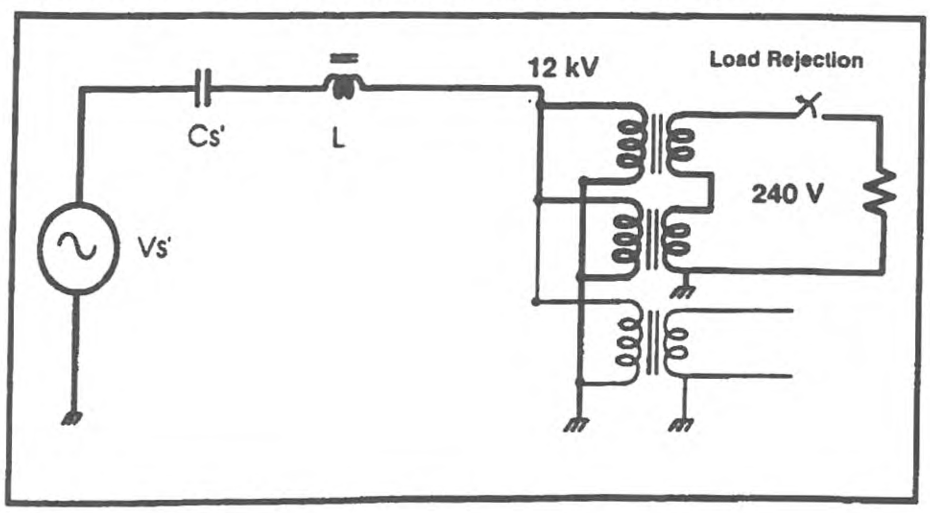


Figure 4.4 Circuit For Load Rejection Test

Explanation

This can be explained as follows: When the system is not loaded, there is no energy stored in the reactive elements (capacitor and reactor) of the circuit (assuming steady state conditions). When the system is loaded and current flows through the reactive elements, a certain amount of energy is stored in the circuit. This energy oscillates between the capacitive and inductive elements at a rate of 100 Hz. That is, when the current is at its peak, the voltages across the reactive elements is zero and thus the energy is all stored in the inductance. When the voltage across the reactive elements is at its peak, the current is zero and thus all the energy is stored in the capacitance. The problem arises when the load is completely switched off. The current is interrupted at the zero crossing and at that instant, the voltage across the capacitance is at its peak. This results in having a trapped charge on the capacitance which discharges through the magnetising impedance of the transformers. As there is no damping left in the circuit, this load rejection results in the same behaviour as described for system energisation.

Solution

It was found that the low voltage filter is also suitable for solving this problem. (Compare Figure E9 with Figure E11). The filter damps the transient oscillation within one cycle.

4.2.3 Fault Response

If a short circuit is applied to the output of the system, the voltage on the shield wire climbs until it is either clamped by the surge arrester or a flashover across the insulator spark gaps results. In this case the spark-gaps flashed over first (see figure E6). The voltage climbed to a value of 100 kV peak and then flashed over. This occurred repeatedly until the protection closed the earth switch.

As described earlier, it is desirable to have the voltage on the shield wire clamped by the surge arrester during short circuit conditions on the output of the system. In this case the flashover voltage of the shield wire insulator spark gaps was reached before the voltage could be clamped by the surge arrester. In future, the spark-gap flashover voltage should be set higher than the knee point voltage of the surge arrester.

4.2.4 Line Trip / Re-energise

Another transient event which was tested was the behaviour of the system if the transmission line is switched out and back in again. The voltage was measured on the secondary side of the transformers during a line trip and energisation (see figures E15 & E16). The concern was that line switching might produce a situation where the induced voltage on the shield wire is higher than normal. This would be due to lack of cancellation by the distant phase conductors if the closest phase was energised and the others not for any length of time. It was found that during normal switching, the pole scatter (time difference in circuit breaker closing instants between phases) was within one cycle, which gives the system little time for any over voltage to develop.

4.3 Protection Performance

This section describes the performance of the protection system and highlights the short fall areas which need attention in future.

4.3.1 Response Time

The speed with which the protection circuit closes the earth switch during a fault condition was measured and found to be ± 250 ms (see Figure E6). This is considered acceptable, as the fault current and consequent voltages of the system are limited by the mechanisms shown in Figure 3.3.

4.3.2 Weak Links

Pneumatic Switch and Gas Leaks

One problem was that there were leaks in the gas pipes used for the pneumatic switch which were difficult to find at the top of a wood pole 10 m above the ground. It is suggested that in future such a system should either use another means of driving the switch, or the switch should be mounted closer to the ground, where it is easier to do maintenance and repairs.

4.3.3 Consequences of Protection System Failure

The most onerous condition is a short circuit on the output of the system as described earlier. If the protection system were to fail under such conditions, it is necessary to know what the consequences would be for the rest of the system.

Earth Switch Doesn't Close During Fault

If the earth switch doesn't close for any reason during a short circuit on the output of the system, the following possibilities exist:

- The surge arrester before the reactor will eventually over heat due to continuous conduction of current and thermal run-away will result. The surge arrester will not explode as it would in a power system, due to the high source impedance which limits the fault current. The surge arrester may become a short circuit and thus effectively ground the shield wire. No further damage to the system would result in this case.
- As before except the surge arrester may become an open circuit. This would then allow the fault current to continue as shown in Figure E7 and the voltage on the shield wire would then only be limited by the spark-gaps as in figure E6. This continuous build up and break down of voltage may eventually cause the capacitor insulation to fail. The capacitor may then become a short circuit, carrying a limited fault current. No further damage would result.
- If the capacitor becomes an open circuit, the supply circuit would no longer be tuned to 50 Hz. This would then introduce further impedance into the circuit and the fault current would thus be limited. The reactor will still probably be saturated at this stage and over heating would cause degradation of the internal insulation and possible complete failure of the reactor.
- If the fault current persists, the over current relay may eventually burn out and cause a fire in the protection cabinet.

Note that it is unlikely that any of the system components would explode as can be expected on a normal power network. This is primarily due to the high source impedance of the shield wire, which limits the fault current to the order of amps.

This scenario shows, however, that it is important to have the protection system in good condition at all times. It also illustrates why the basic protection energy systems (battery level and gas bottle pressure) are also monitored, to prevent operation of the system if the protection system is not in order.

4.4 Discussion on Simulation Errors

4.4.1 Line Constants Model and Source Parameter Calculation

Possible Reasons for Discrepancy

- Firstly the section of insulated shield wire was 9.6 km instead of 10 km long.
- The "Line Constants Model" was calculated using the option to simplify the matrices by assuming the earthed shield wire to be continuously at ground potential. It was later discovered that using this approach in ATP (Line Constants Routine) does not give accurate results for steady state calculations concerning the shield wires. When the earthed shield wire is considered as a separate conductor in the "Line Constants Routine" and only earthed in the ATP program, a result much closer to the measured value is achieved. Assuming the same geometries as used before, the simulation yields an induced voltage of 47.6 kV and a source impedance of 67.7 nF for the 9.6 km section of line compared to the measured results of 45 kV and 57 nF.
- The assumption that the Guyed-V tower-top geometry is representative of the whole line may not be accurate enough, even though most towers in the section of the line are this type. The self supporting towers have a significantly different tower-top geometry which may influence the calculation of the source parameters.
- The assumption that the span sags and tower heights could simply be averaged may have produced additional inaccuracies in the calculation. It may be necessary to find a better way to represent the whole section of line with only one span.

4.4.2 System Energisation Behaviour

The main reason why the behaviour of the system, during energisation, was not noticed during the simulation and design phase of the work, was that only the series impedance (all referred to the primary side) of the transformers was used in the ATP model. The magnetising impedance was not considered initially, as it was assumed to be high enough not to have significant influence on the system behaviour. The assumption might only be valid for the steady state behaviour of the system. Saturation of this impedance was completely ignored, but actually becomes very significant at lower frequencies.

5 ECONOMIC CONSIDERATIONS

5.1 Capital Costs

The capital cost is an important factor when considering the viability of such a system. It is necessary to make the system as cost effective as possible so that the application of such systems may be more wide spread.

The capital costs are given as the actual values which were invoiced in the first quarter of 1992 for the experimental system. These costs will decrease with increasing batch size of components.

Table 5.1 Capital Costs of System Components

Component of System	Experimental		Commercial	
	Cost R	% of Total	Cost R	% of Total
Labour for 9.6 km Shield wire Insulation	30 000	21.7	10 000	11.5
Materials for Insulation of Shield wire	5 500	4.0	5 500	6.3
Capacitor	6 150	4.5	4 500	5.2
Reactor	14 000	10.1	14 000	16.0
Surge Arrester	2 200	1.6	2 200	2.5
Current Transformers	4 000	2.9	4 000	4.6
Switch Gear	10 250	7.4	6 250	7.2
3 x Distribution Transformers	7 800	5.6	7 800	9.0
Low Voltage Filter	4 800	3.5	4 800	5.5
Protection Panel (Incl. Battery and Charger)	10 000	7.2	8 000	9.2
Site Construction, Civil Works, Port-a-Camp	43 500	31.5	20 000	23.0
Total Capital Cost	**138 200**	**100.0**	**87 050**	**100.0**

Note that the commercial cost is based on estimates of what some component costs might be for production in larger batch sizes. It is also assumed that the shield wire will be insulated during the construction of the line and that a more economic construction arrangement will be used.

5.2 Important Cost Influencing Factors

Note that the two most costly items are the "labour for insulating the shield wire" and the "construction, civil works and port-a-camp". If these can be significantly reduced, a large impact can be achieved on the overall cost of the system.

5.2.1 Labour for the Insulation of the Shield wire

If the shield wire is insulated during the construction of the transmission line, the labour cost component is almost completely eliminated. If the insulation has to be retro-fitted, the cost of "live-line" labour (which will invariably be required) is prohibitively high. It is clear that planning has an important impact on the overall cost of such a power supply system.

5.2.2 Civil and Steel Work

For the proto-type system, ESKOM standard steel equipment supports and foundations were used. A fence, yard stone and a port-a-camp building were also used. These add up to be costly components compared to the rest of the system. In future, a more sparing approach should be used. For example, a single steel structure could be used to support all the main components and an anti-climbing device used to prevent tampering. This would eliminate the need for a fence and yard stone. It will also not be necessary to have a building structure to house the protection relay panel which will be mounted in an out-door steel cabinet.

5.3 Maintenance Considerations

The system will be expected to operate in remote areas where there may not be an infrastructure for maintaining power supply systems of any nature (e.g. Servitudes in neighbouring countries). For this reason it is necessary to design the system to be maintenance free where possible.

Components which may require maintenance or periodic replacement should be standard, off-the-shelf items. Components of this nature would include the 12 V battery for the protection system and the gas bottle for driving the switch gear. These components should be positioned such that access for maintenance is easy, bearing in mind that it should also be tamper-proof. It would be cost effective to train some body in the locality of the supply system to do this type of maintenance.

The main components of the system, such as the reactor, capacitor and CTs are hermetically sealed and should require no maintenance. The protection panel uses electro-mechanical relays which should be robust and fail-safe and thus require no maintenance.

In the event of a major component failure, the proper personnel would have to be called in to conduct the repairs. This would be both costly and time consuming, so every effort should be made to design the system to be fail-safe.

5.4 Cost Recovery

The capital cost of this type of supply system could be recovered in the same way that it is for distribution lines. A tariff is structured such that the consumer (such as a farmer) pays a fixed component each month based his share of the capital cost of the distribution line. The consumer pays back the capital cost over a period of 25 years in the same way as one would pay off a home loan. The consumer also pays a variable component, based in his energy usage during the month.

From a cost point of view this type of power supply system could be compared with three or four kilo metres of 22 kV or 11 kV distribution line, depending on its ultimate commercial cost.

The system will be much more cost effective than a conventional substation with electromagnetic voltage transformation for the small loads anticipated,. The system will also be favoured over diesel generators which have high running costs and relatively short life spans. Solar energy systems are also more limited in the type of loads which can be driven.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Main Conclusions

The following conclusions have been reached concerning the viability of using insulated lightning shield wires and series compensation to tap power from high voltage transmission lines:

- This project has shown that it possible to get an electricity supply from insulated lightning shield wires on a 400 kV transmission line. The method of series reactive compensation was evaluated for its fundamental characteristics and a system designed which gives a reliable and desirable performance. The behaviour of the system was measured and explained, and were problems were encountered, solutions were either implemented and tested or recommended for future application. The viability of such a system is however subject to a number of important considerations.
- Once a system is designed to give maximum power output per unit length of insulated shield wire, it is not possible to increase the output capacity of the system.
- It is necessary to have an accurate model of the equivalent source parameters of the insulated section of shield wire before designing a shield wire tap-off supply system. Only then can a system be designed with known output capabilities and associated costs. This also means that the system cannot be standardised as a whole and applied on any transmission line.
- The system must be designed taking into account all possible steady state and transient conditions. The components must be able to withstand all voltage and current stresses that may be expected in practice.
- The output voltage of the system should conform to the relevant standards concerning maximum over voltages applied to domestic consumers under all operating conditions. It would not be favoured if consumers' appliances were regularly damaged due to excessive over voltages.
- The system should have a low cost, but reliable protection system, which would protect the system from self destruction in the event of faults. The protection system should not compromise the reliability of the main system.
- The system should in no way compromise the reliability of the main transmission line. The insulator fittings used to insulate the shield wire should be carefully rated (structurally) and the new geometry should still be acceptable from a lightning shielding point of view.
- The economic feasibility of such supply systems will have to be evaluated for individual applications based on a more acceptable commercial cost. There are many areas in the experimental system where costs can be cut in order to make the system more viable.
- The capital cost of such a system could be recovered using an existing tariff structure where the capital is recovered over 25 years such as for distribution lines in rural areas.

6.2 Recommendations for Future Work

This research project has shown that power can be suitably tapped from insulated lightning shield wires on HV transmission lines using series compensation. Refinement of a number of areas would however lead to a more technically and economically viable system. This project only looked at tapping power from a 400 kV transmission line. Further research on the following topics would greatly enhance the practicality of this type of power supply:

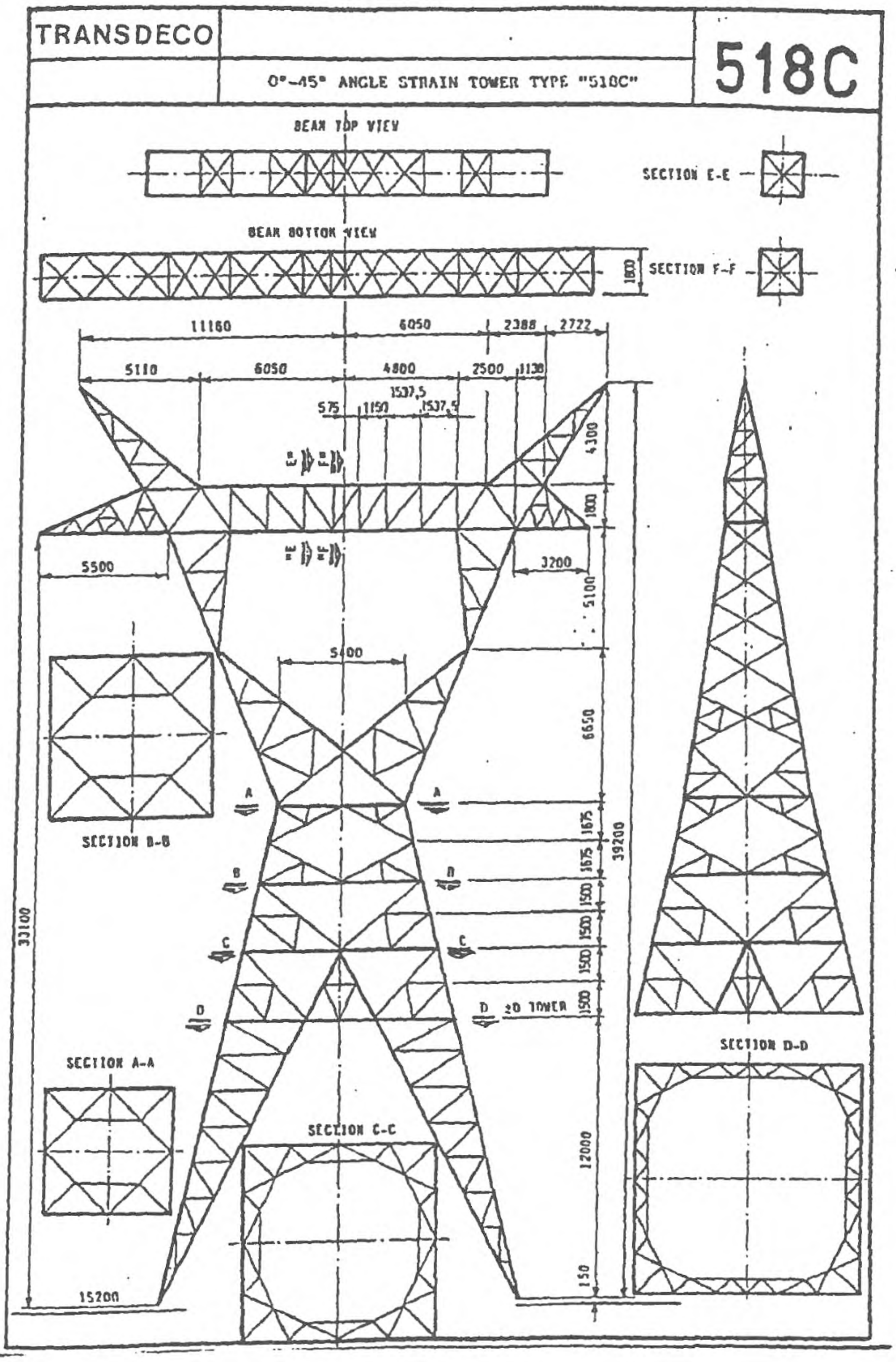
1. A suitable method for calculating the exact shield wire source parameters should be developed. This method should have a definite way of taking the varied transmission line geometries over the length of the insulated section into account. This is necessary as this type of system (using series compensation) is sensitive to variations in the source parameters.
2. The economic trade-off for obtaining more power from any single shield wire supply system should be investigated. More power can be achieved by one of the following approaches:
   - Insulate a longer section of shield wire.
   - Increase the insulation level of the shield wire (if possible) and increase the current ratings of the equipment.
   - Replace the standard shield wire conductor of the insulated section with one which has a larger diameter.
3. The technical and economic trade-offs for selecting a standard voltage for the system output should be investigated. The difference between starting with a high standard voltage and a low one should be explored and quantified.
4. The protection philosophy should be refined to incorporate standard components where possible and still be fit for purpose and economical.
5. The construction of the system can also be refined. The possibility of constructing the whole system in one oil-filled or SF_6 filled container should be explored. This would make the system much easier to install and it would possibly be safer.
6. There may be ways in which certain components can be standardised. This would make the system more economically viable. This process may include looking at reactors with tapped windings to allow for variations in the source parameters.
7. The possibility of using thyristors for switching the system on and off should be investigated. This would allow point-on-wave switching which could eliminate undesirable transients when the system is energised.
8. The feasibility of using a single wire earth return (SWER) reticulation scheme in conjunction with this type of supply system can also be studied. This would improve the overall viability of implementing this type of scheme.
9. The effects of insulating sections of the shield wire on a transmission line on the performance of the high frequency communication signals which are used for protection purposes should be studied in more depth.

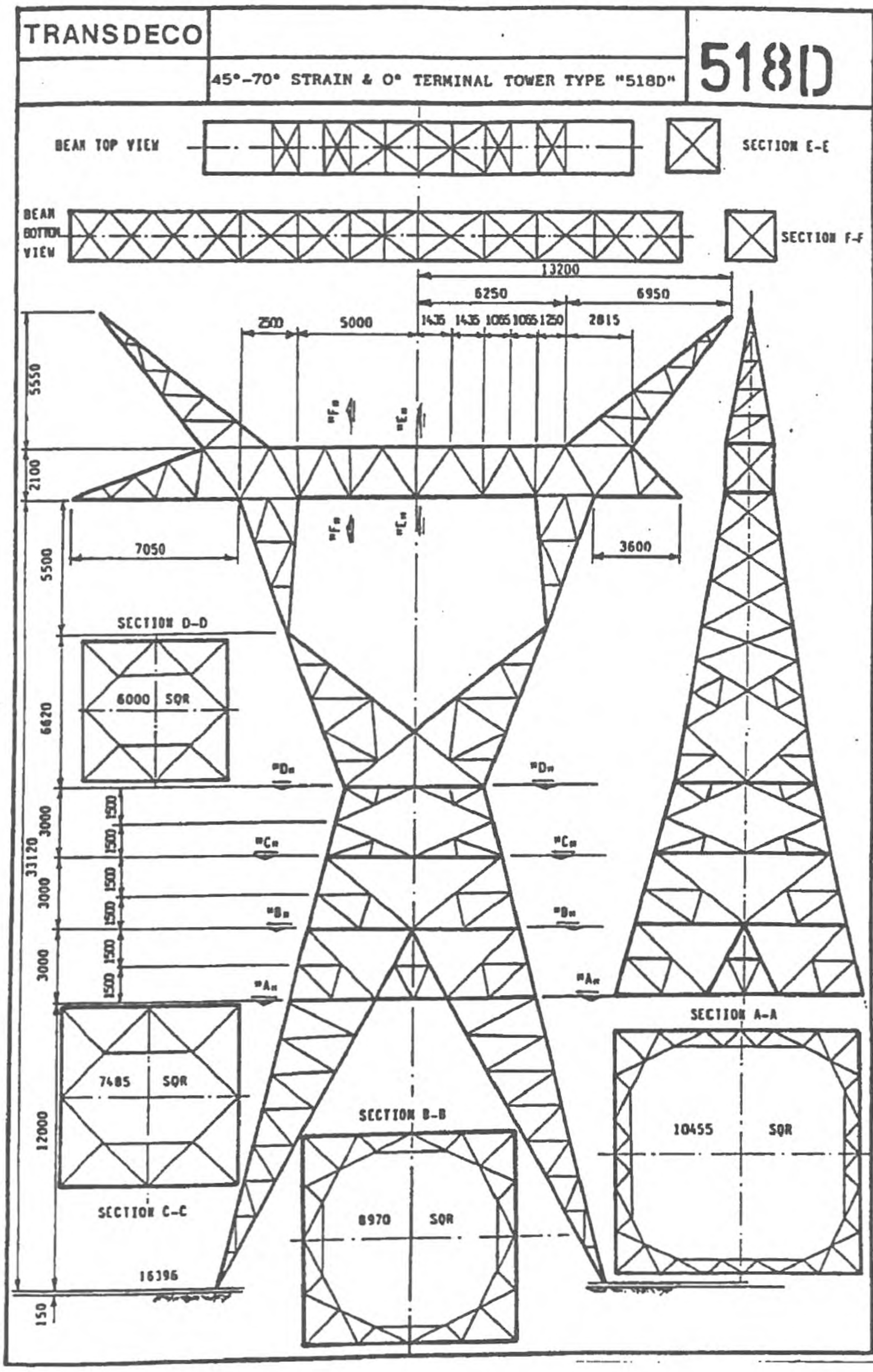
APPENDIX A TRANSMISSION LINE PROFILE DIMENSIONS

Table A1 Transmission Line Profile Dimensions For Insulated Section

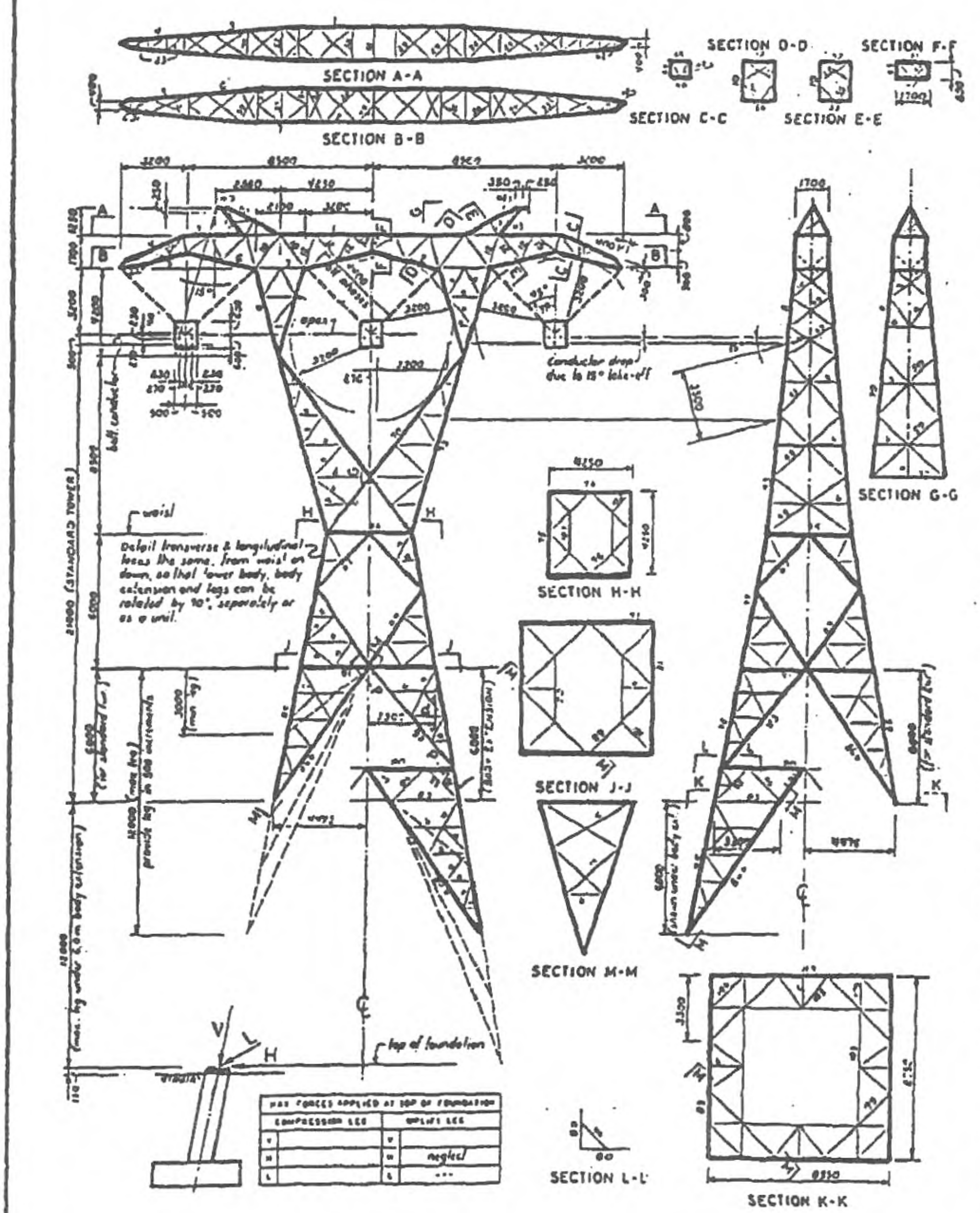
Tower			Phase Conductors		Shield wire	
No.	Type	Span (m)	Height at Tower (m)	Sag (m)	Height at Tower (m)	Sag (m)
155	518D	409.6	18	10.74	25.65	9.41
156	520B	351.0	27	7.88	32.98	6.91
157	520B	333.0	18	7.1	23.98	6.22
158	520B	508.0	18	16.53	23.98	14.48
159	518H	644	43	26.58	48.98	23.27
160	518H	536	43	18.4	48.98	16.12
161	518H	470	28.5	14.14	34.48	12.39
162	520B	468	28.5	14.02	34.48	12.29
163	518C	411.7	24	10.55	30.1	9.55
164	520B	426	24	11.3	29.98	10.22
165	520B	446	24	12.4	29.98	11.2
166	520B	473.4	28.5	13.96	34.48	12.62
167	518C	416.3	25.5	11.01	31.6	9.75
168	520B	394.0	19.5	9.87	25.48	8.74
169	520B	468.0	22.5	13.92	28.48	12.33
170	520B	508.0	30.0	16.41	35.98	14.52
171	518C	462.0	30.0	13.63	36.1	12.05
172	520B	475.0	28.5	14.36	34.48	12.69
173	520B	425.1	28.5	11.5	34.48	10.17
174	518C	403.9	23.5	10.07	29.6	9.24
175	520B	425.0	24	11.15	29.98	10.23
176	520B	204.0	28.5	2.57	34.48	2.36
177	518C	346.0	31.5	7.22	37.6	6.81
178	518C		25.5		31.6	

APPENDIX B DIAGRAM OF TRANSMISSION LINE TOWERS USED

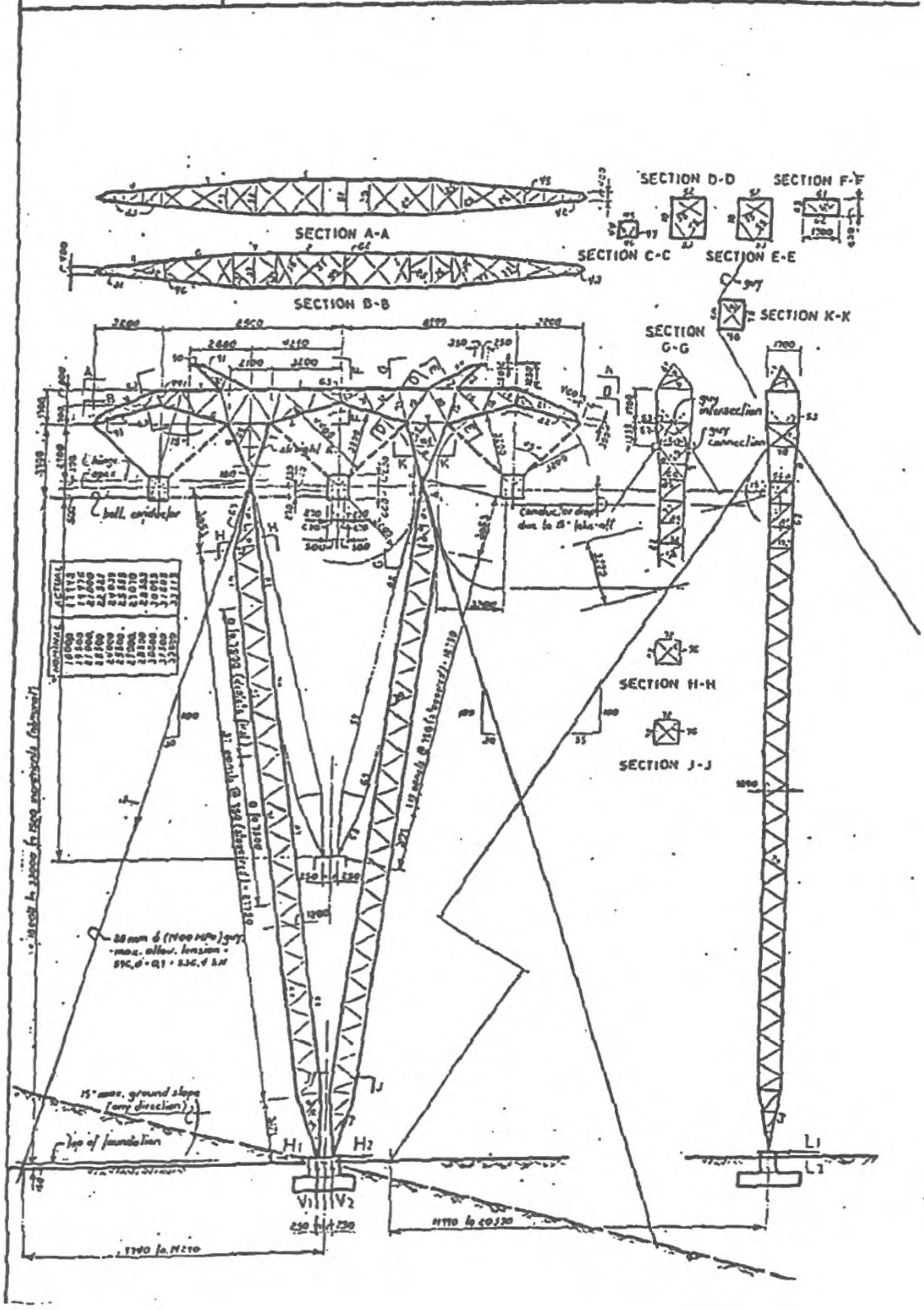

TRANSDECO
518C
0°-45° ANGLE STRAIN TOWER TYPE "518C"
BEAM TOP VIEW
BEAM BOTTOM VIEW
SECTION E-E
SECTION F-F
SECTION B-B
SECTION A-A
SECTION C-C
SECTION D-D
11160
6050
2388
2722
5110
6050
4800
2500
1138
575
1150
1537,5
1537,5
4300
1800
5500
3200
5100
5400
6650
1675
1675
1500
1500
1500
1500
12000
150
39200
33100
15200
±0 TOWER


TRANSDECO
45°-70° STRAIN & 0° TERMINAL TOWER TYPE "518D"
518D
BEAM TOP VIEW
SECTION E-E
BEAM BOTTOM VIEW
SECTION F-F
13200
6250
6950
2500
5000
2815
7050
3600
SECTION D-D
6000 SQR
7485 SQR
SECTION C-C
SECTION B-B
8970 SQR
SECTION A-A
10455 SQR
16396
5550
2100
5500
6620
3000
3000
3000
33120
12000
150

TRANSDECO		518H
	SELF-SUPPORTING SUSPENSION TOWER TYPE "518H"	



TRANSDECO		DATE 520B
	400KV GUYED SUSPENSION TOWER TYPE "520B"	



APPENDIX C ATP COMPUTER PROGRAM LISTING

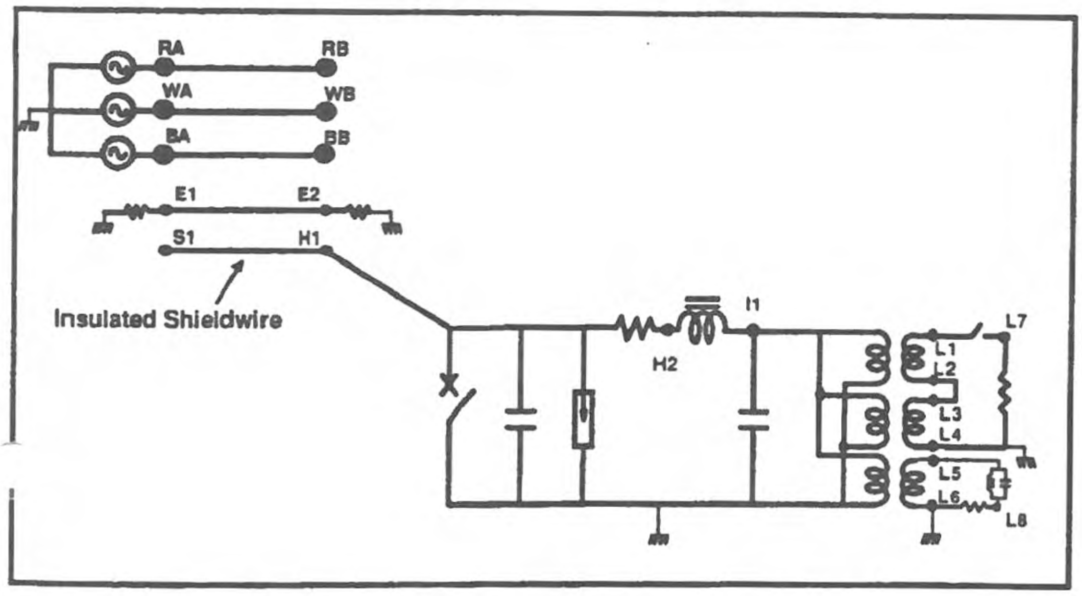


Figure C1 Circuit Model Used for ATP Simulations Showing Node Names

```
BEGIN NEW DATA CASE
C
C /\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/
C
C          --  LINE CONSTANTS SUBROUTINE --
C
C
C          --  400 KV QUAD ZEBRA
C
C /\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/
$ERASE
C
C ***** USE LINE CONSTANTS TO DERIVE LINE PARAMETERS. [P113] *****
LINE CONSTANTS
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
BRANCH  RA    RB    WA    WB    BA    BB    S1    H1
C **** DETERMINE UNITS  "METRIC" OR "ENGLISH". ****
METRIC
C
C ***** CONDUCTOR CARDS *****
C
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C ][SKN][ RESIS][][ REACT][ DIAM ][ HORIZ][VTOWER][ VMID ][ SEPAR][ALPH][NAME][
  1.3000 0.0687  4            2.891     -8.500 30.000    16.744     38.0  0.0        4
  2.3000 0.0687  4            2.891      0.000 30.000    16.744     38.0  0.0        4
  3.3000 0.0687  4            2.891      8.500 30.000    16.744     38.0  0.0        4
  4.5000 1.8000  4            1.355     -7.130 35.028    23.263
C 0.5000 1.8000  4            1.355     -7.130 35.600    23.835
  5.5000 1.8000  4            1.355      7.130 35.600    23.835
C
BLANK ENDING CONDUCTOR CARDS
C
C ***** FREQUENCY CARDS *****
C        1         2         3         4         5         6         7
C 3456789012345678901234567890123456789012345678901234567890123456789012345678
C  RHO ][  FREQ  ][  FCAR  ] [ICPR] [IZPR] ![ DIST ] [IP]!![C][T][N][][]
   500.0     50.E0           1                    .      10.        1         44 1-9
C  500.0    50.00            1    111 111    0                      1            1-2
C
BLANK ENDING FREQUENCY CARDS
$PUNCH
BLANK ENDING "LINE CONSTANTS".
C
BEGIN NEW DATA CASE
BLANK INDICATING TERMINATION-OF-RUN
```

```
 GIN NEW DATA CASE
C
C /\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/
C
C          -- ELECTROMAGNETIC TRANSIENTS PROGRAM --
C     COUPLING BETWEEN 400 KV LINES AND SINGLE INSULATED SHIELD WIRE
C
C           LEIGH STUBBS    2/8/91
C
C /\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/
C
C ***** PLOTTER PAPER HEIGHT ADJUSTMENT *****
C
C 34567890123456789012345678901234567890123456789O
C
C
C ***** MISCELLANEOUS DATA PARAMETER CARDS *****
C
C 345678901234567890123456789012345678901234567890123456789012345678901234567890123456789
C DELTA][ TMAX ][ XOPT ][ COPT ][EPSILN][TOLMAT]
 5.0E-4-300.E-3      0.0      0.0  1.0E-8  1.0E-8
C
C          1         2         3         4         5         6         7
C 345678901234567890123456789012345678901234567890123456789012345678901234567890123456789
C IOUT ][ IPLOT][IDOUBL][KSSOUT][MAXOUT][ IPUN ][MEMSAV][ ICAT ][NENERG][IPRSUP
     20       2       0       1       0       0               0
C
C *************************************************************************
C ***** BRANCH CARDS *****
C [NODE][NODE][REF1][REF2][ROHM][L MH][C UF]
  S1                        0.01                                                  3
  E1                        0.01                                                  3
  E2                        0.01                                                  3
  S1     H1                                .054
  H1                                       .110
  H1     H2               280.0
  H2     I1                    45.0E3
  I1                                        .035
C ***  ********************************************************************
C TRANSFORMER SECONDARIES 230V
C ********FILTER ELEMENTS**********
C
C  ****SATURABLE REACTOR******
C C        1         2         3         4         5         6         7
C C 345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
C C FREQU][V BASE][P BASE][IPUNCH][KTHIRD]
     50.0     .2306669.E-6        0
C C        1         2         3         4         5         6         7
C C 345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678
C C  I RMS PU     ][  V RMS PU     ]
C            1.000    1.000
C            1.100    1.100
C            1.600    1.300
C            3.500    1.500
C             9999
C SATURABLE AT 1.1 PU
C [NODE][NODE][REF1][REF2][CURR][FLUX]
  L5     L8                      41.0 1.0354                                      3
 4.10060446E+01  1.03536376E+00
 4.51066490E+01  1.13890014E+00
 7.83160049E+01  1.34597289E+00
 2.06118738E+02  1.55304565E+00
            9999
C [NODE][NODE][REF1][REF2][ROHM][L MH][C UF]
C L5     L8                      25.25                                            3
```

```
C L5     L8                                  400.                             3
C L8     L6                   5.0                                             3
C L2     L3                   0.02
C L7     L4                   4.84
C L4                          0.1
C L6                          0.1
C
C ************************************************************************
C *****SATURABLE REACTOR******
C [NODE][NODE][REF1][REF2][CURR][FLUX]
98H2     I1                  3.8470173.76                                     3

  3.84695399E+00  1.73761049E+02
  9.47294539E+00  2.25889364E+02
            9999
C 345678901234567890123456789012345678901234567890123456789012345678901234567890
C        1         2         3         4         5         6         7         8
C ************************************************************************
C ****TRANSFORMER 1****  ||    I||FLUX|BUSTOP|RMAG||                      FLAG
  TRANSFORMER                0.22  0.57   TR1     1.E6                        3
C             I|              FLUX
  2.22233560E-01  5.67199279E-01
  4.63837344E-01  7.54375041E-01
  1.58345619E+00  1.03797468E+00
            9999
C | LV1|| LV2|               |    R||    L||VRAT||                          IP
 1L1     L2                    1.0  .001231.0                                 3
C | HV1|| HV2|               |    R||    L||VRAT||
 2I1                         756.0 3300.022000.
C ************************************************************************
C ****TRANSFORMER 2****  ||    I||FLUX|BUSTOP|RMAG||                      FLAG
  TRANSFORMER                0.22  0.57   TR2     1.E6                        3
C             I|              FLUX
  2.22233560E-01  5.67199279E-01
  4.63837344E-01  7.54375041E-01
  1.58345619E+00  1.03797468E+00
            9999
C | LV1|| LV2|               |    R||    L||VRAT||                          IP
 1L3     L4                    1.0  .001231.0                                 3
C | HV1|| HV2|               |    R||    L||VRAT||
 2I1                         756.0 3300.022000.
C
C ************************************************************************
C ****TRANSFORMER 3****  ||    I||FLUX|BUSTOP|RMAG||                      FLAG
  TRANSFORMER                0.22  0.57   TR3     1.E6                        3
C             I|              FLUX
  2.22233560E-01  5.67199279E-01
  4.63837344E-01  7.54375041E-01
  1.58345619E+00  1.03797468E+00
            9999
C | LV1|| LV2|               |    R||    L||VRAT||                          IP
 1L5     L6                    1.0  .001231.0                                 3
C | HV1|| HV2|               |    R||    L||VRAT||
 2I1                         756.0 3300.022000.
C ************************************************************************
C 22KV TRFR  ZNO ARRESTER                     27,0KV RATED
C ************************************************************************
C  Rating =   67700.0   V-mult =  1.00000E+00   I-mult =  1.00000E+00    Gapless
92I1                                         5555.                            4
C            V-reference                     V-flashover
  6.7700000000000000E+04  -1.0000000000000000E+02
C             Multiplier                      Exponent                    V-min
  3.6265130105131560E+10    5.3847674829240660E+01    5.6000000000000020E-01
  8.5661866067531460E+04    2.7636758611426140E+01    6.1000000000000100E-01
  2.8893105776224240E+08    4.7403000081153100E+01    6.6299999999999940E-01
```

```
 3.5149319184147760E+06   3.5236610483090990E+01   6.9599999999999870E-01
 1.3416316478678210E+05   2.4243117093160190E+01   7.4299999999999900E-01
 2.3499530618195560E+04   1.6569259073089050E+01   7.9690930821790150E-01
 1.0065618956631920E+04   1.0932527737670280E+01   8.6034994851113230E-01
 1.0288923703708550E+04   5.4402883327541930E+00   1.0040031548949460E+00
                     9999
C **************************************************************************
C 60KV   ZNO ARRESTER   141KV 10KA DISCHARGE VOLTAGE
C **************************************************************************
C [NODE][NODE][REF1][REF2]               [     ]
92H1                                      5555.                               3
C               V-reference                V-flashover
 1.4100000000000000E+05  -1.0000000000000000E+02
C                Multiplier                     Exponent                   V-min
 2.8893105776233690E+08   4.7403000081154080E+01   6.5337586272252450E-01
 3.5149319184147760E+06   3.5236610483090990E+01   6.9600000000000020E-01
 1.3416316478678210E+05   2.4243117093160190E+01   7.4299999999999900E-01
 2.3499530618195560E+04   1.6569259073089050E+01   7.9690930821790150E-01
 1.0065618956631920E+04   1.0932527737670280E+01   8.6034994851113230E-01
 1.0288923703708530E+04   5.4402883327541580E+00   1.0040031548949450E+00
                     9999
C **************************************************************************
C ***** DISTRIBUTED PARAMETER LINE MODEL *****
C **************************************************************************
$VINTAGE, 1
-1RA      RB                  1.96340E-01 7.79543E+02 1.92597E+05-10.0000E+00 1  5
-2WA      WB                  1.73505E-02 2.70993E+02 2.95779E+05-10.0000E+00 1  5
-3BA      BB                  1.73244E-02 2.17572E+02 2.97802E+05-10.0000E+00 1  5
-4S1      H1                  1.42219E+00 4.40376E+02 2.77362E+05-10.0000E+00 1  5
-5E1      E2                  1.72531E+00 4.34512E+02 2.94525E+05-10.0000E+00 1  5
$VINTAGE, 0
 0.60797206  0.70707325  0.40892498 -0.26920050  0.15744264
 0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
 0.51003343 -0.00004877 -0.81580238 -0.24855838  0.01023205
 0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
 0.60810250 -0.70713750  0.40895805 -0.26712667 -0.13049364
 0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
 0.01475643  0.00146386  0.00029555  0.60976003 -0.71446104
 0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
 0.01514850 -0.00135156  0.00027108  0.65006605  0.66904704
 0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
C **************************************************************************
                                        RHO=2000
C 345678901234567890123456789012345678901234567890123456789012345678901234578
C  RHO ][  FREQ  ][  FCAR  ] [ICPR] [IZPR] ![ DIST ] [IP]!![C][T][N][][]
  2000.0     50.E0          1     111 111    1                            1-9
   The transformation matrix was calculated at  5.00000000E+01 Hz.
VINTAGE, 1
1RA      RB                  1.53249E+00 4.33893E+02 1.91034E+05-10.0000E+00 1  4
2WA      WB                  3.42407E-01 7.00450E+02 1.81905E+05-10.0000E+00 1  4
3BA      BB                  1.78854E-02 2.69064E+02 2.94358E+05-10.0000E+00 1  4
4S1      H1                  1.72981E-02 2.17235E+02 2.97578E+05-10.0000E+00 1  4
VINTAGE, 0
-0.28806588  0.55502167  0.72454055 -0.39294029
 0.07033680  0.05064180 -0.01869259 -0.01960562
-0.16767354  0.50991445 -0.01840900  0.81487068
 0.06382085  0.02359678  0.02055410 -0.00005910
-0.07520405  0.64288405 -0.68810823 -0.42532016
 0.08003394 -0.00346799 -0.02085135  0.01737861
-0.93156778  0.01525506  0.00139545 -0.00027383
 0.00191445 -0.12358052 -0.00074997  0.00001393

C **************************************************************************
C ***** NOMINAL PI MODEL MODEL ****
C ***** EARTH WIRE REDUCED INTO MODEL**************
```

```
C ********************************************************************************
$UNITS, 50.0,50.0
C C  RHO ][  FREQ  ][  FCAR  ] [ICPR] [IZPR] ![ DIST ] [IP]!![C][T][N][][]
C   1000.0      50.E0         1                    10.       1        44 1-9
$VINTAGE, 1
 1RA    RB                 1.05977091E+00  5.77235848E+00  3.77521516E+01
 2WA    WB                 9.34251190E-01  3.30079084E+00 -8.05178889E+00
                           1.16078730E+00  5.70826147E+00  3.91986920E+01
 3BA    BB                 9.65445909E-01  2.84558439E+00 -2.51971863E+00
                           1.02245205E+00  3.24583054E+00 -8.11321247E+00
                           1.23304037E+00  5.66385283E+00  3.75958299E+01
 4S1    H1                 9.00531962E-01  3.51190790E+00 -6.53069956E+00     3
                           9.49964623E-01  3.22765548E+00 -3.78788672E+00
                           9.82317483E-01  2.84351751E+00 -1.61761074E+00
                           1.89156713E+01  7.95370953E+00  2.20483053E+01
C
$UNITS, 50.0,50.0
C ********************************************************************************
$ENABLE
C ********************************************************************************
C ***** NOMINAL PI MODEL MODEL ****
C ***** EARTH WIRE NOT REDUCED INTO MODEL**************
C ********************************************************************************
$UNITS, 50.0,50.0
C C         1         2         3         4         5         6         7
C C 345678901234567890123456789012345678901234567890123456789012345678901234567
C C  RHO ][  FREQ  ][  FCAR  ] [ICPR] [IZPR] ![ DIST ] [IP]!![C][T][N][][]
C   500.0       50.E0         1                    10.       1        44 1-9
$VINTAGE, 1
 1RA    RB                 6.56134996E-01  5.90863979E+00  3.77962122E+01
 2WA    WB                 4.82888771E-01  3.46776623E+00 -8.03480294E+00
                           6.56201204E-01  5.90841118E+00  3.92036517E+01
 3BA    BB                 4.82713832E-01  3.03271522E+00 -2.51645792E+00
                           4.82888771E-01  3.46776623E+00 -8.11341596E+00
                           6.56134996E-01  5.90863979E+00  3.75947875E+01
 4S1    H1                 4.81497231E-01  3.66988386E+00 -6.61127270E+00
                           4.81474226E-01  3.41050832E+00 -3.80604375E+00
                           4.81321173E-01  3.04344099E+00 -1.61200793E+00
                           1.84807055E+01  8.10999414E+00  2.20926351E+01
 5E1    E2                 4.81187130E-01  3.03560173E+00 -1.62995410E+00
                           4.81332176E-01  3.38566860E+00 -3.72240334E+00
                           4.81355226E-01  3.61561189E+00 -6.25181345E+00
                           4.79870233E-01  3.14539222E+00 -1.52878637E+00
                           1.84804018E+01  8.11040269E+00  2.18818014E+01
$UNITS,0.0,0.0
C ********************************************************************************
BLANK ENDING BRANCH CARDS
C ********************************************************************************
C *****SWITCH CARDS*******
C
C
C 34567890123456789+1234567890123456789012345678901234567890123456789012345678
C [NODE][NODE][ T CLOSE][ T OPEN ][I MARGIN][FLASHOVR][SPECIALR][REF1][REF2]
C H1            -15.0E-03  10.0E-03          0.0

C L1      L7     200.0E-03 250.0E-03
C ********************************************************************************
BLANK ENDING SWITCHES
C ********************************************************************************
C
C
C ***** SOURCE CARDS *****
C 345678901234567890123456789012345678901234567890123456789012345678901234567
C [NODE][][  AMPL  ][  FREQ  ][   T0   ][   A1   ][   T1   ][ TSTART ][ TSTOP
14RA         342928.6      50.0       0.0                           -1.0    2.0    3
14WA         342928.6      50.0     120.0                           -1.0    2.0    3
14BA         342928.6      50.0     240.0                           -1.0    2.0    3
```

```
C -4S1          65054.0      50.0      0.0                              -1.0   2.0
C
C ****************************************************************************
B NK ENDING SOURCES
C ****************************************************************************
C
C ***** NODE VOLTAGES *****
C
C 3456789012345678901234567890123456789012345678901234567890123456789012345678 9
C [NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE][NODE
  -1    I1    H1
BLANK ENDING NODES
C
C ***** PLOTTING ROUTINE CARDS *****
C
BLANK ENDING PLOTTING ROUTINE
C
BEGIN NEW DATA CASE
BLANK INDICATING TERMINATION-OF-RUN
```

APPENDIX D SIMULATION RESULTS

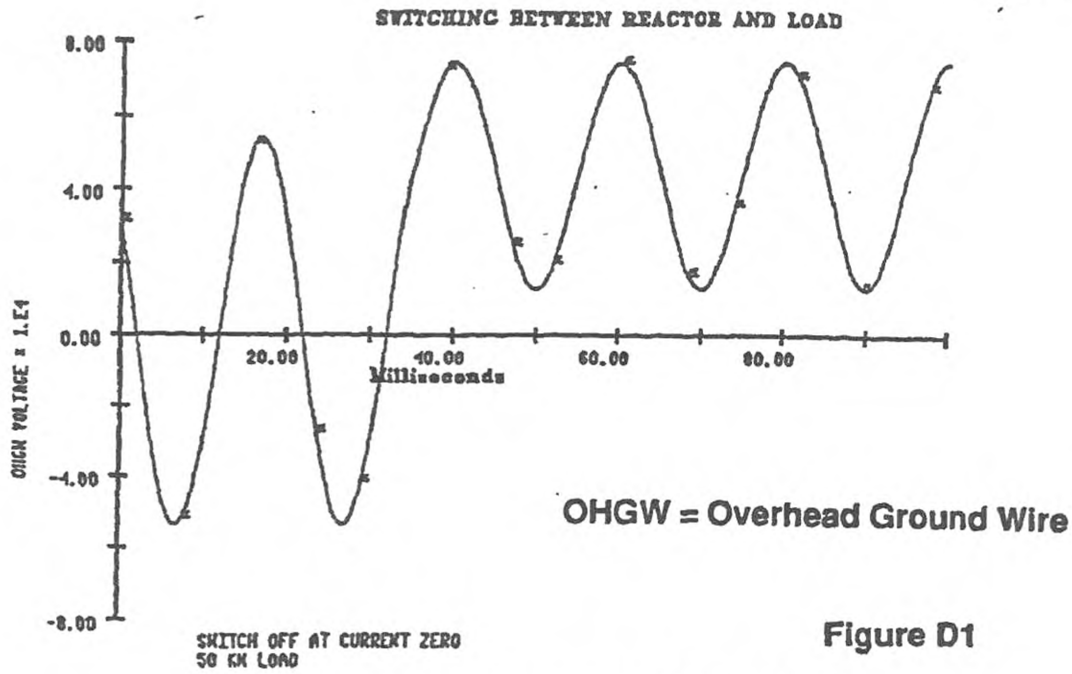


Figure D1

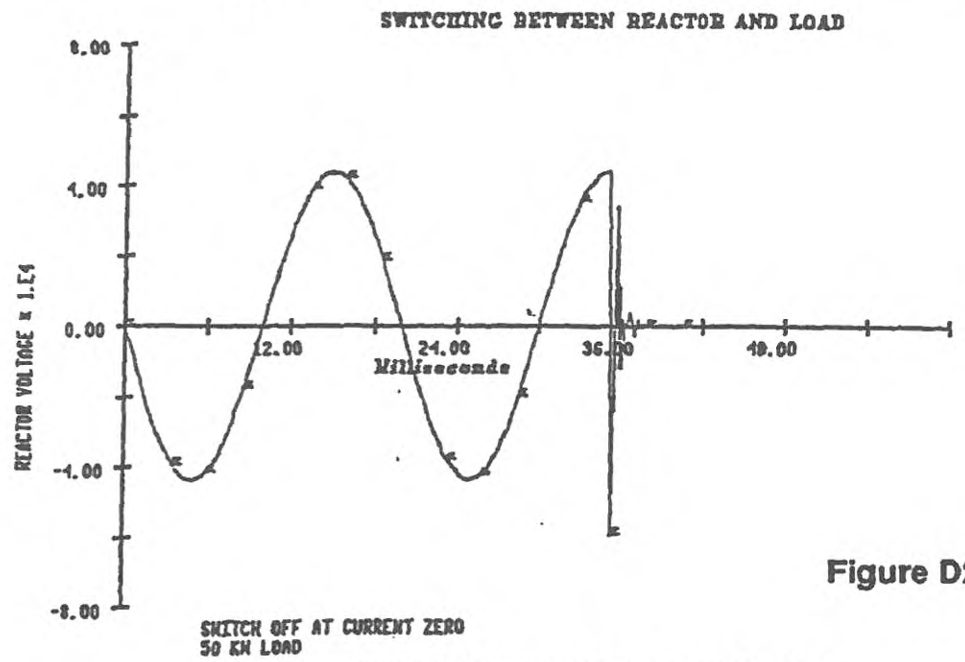


Figure D2

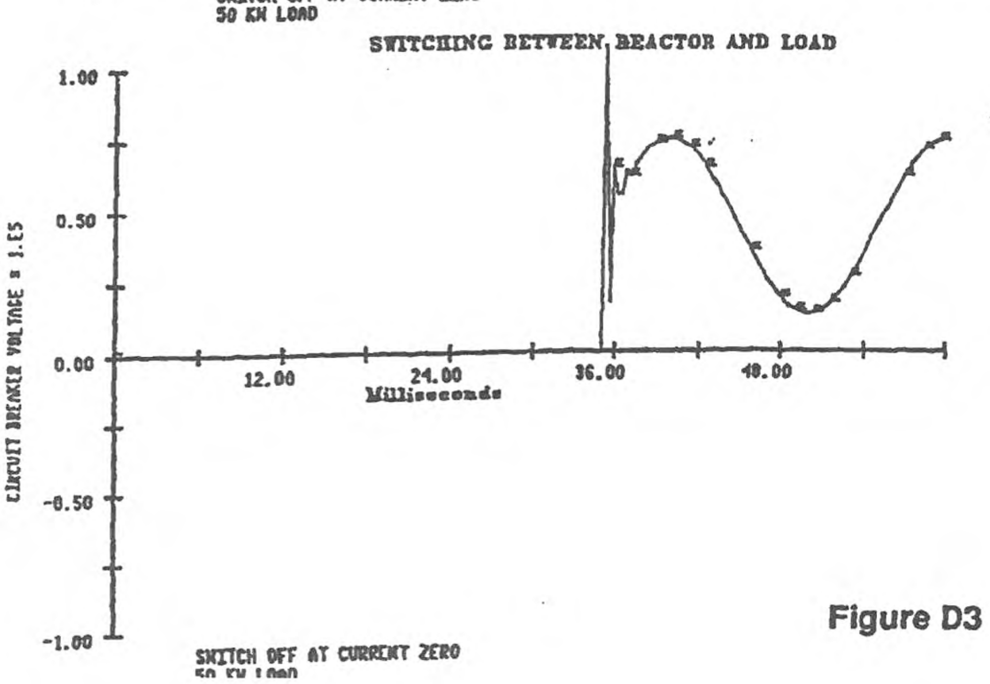


Figure D3

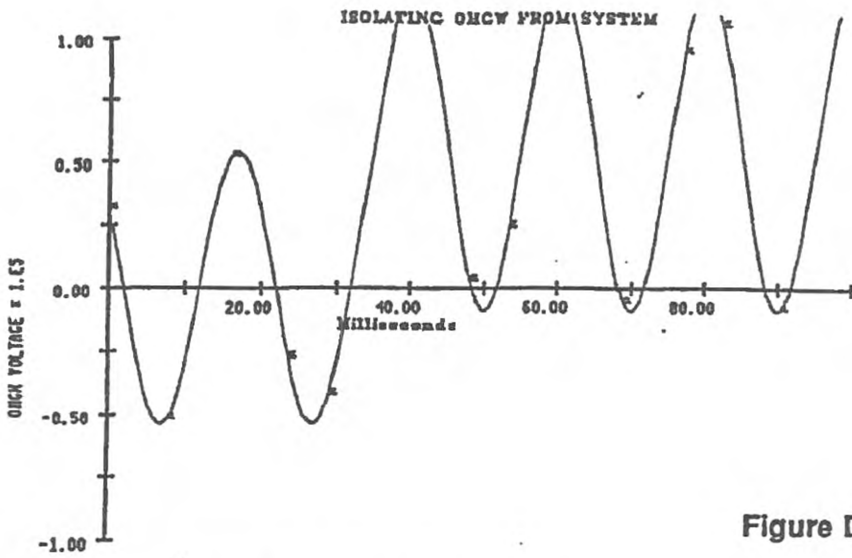


Figure D4

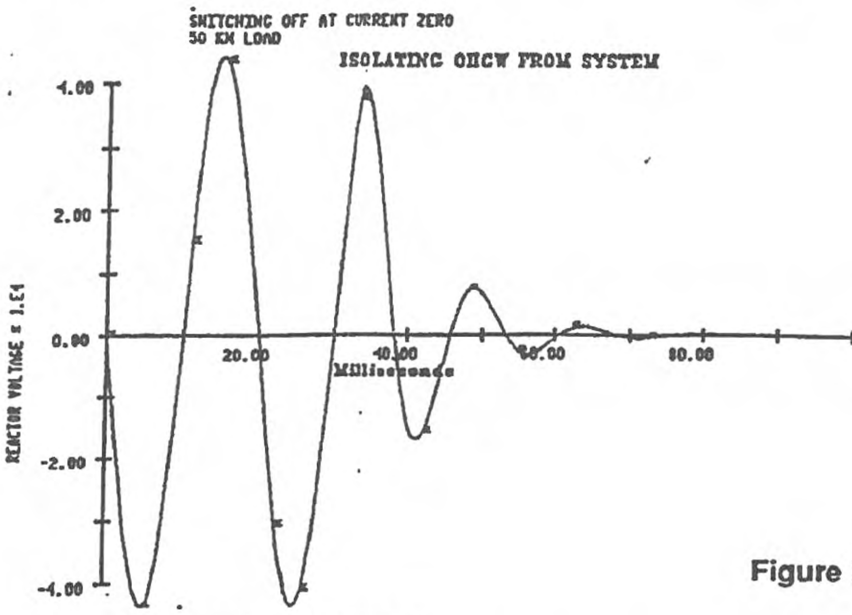


Figure D5

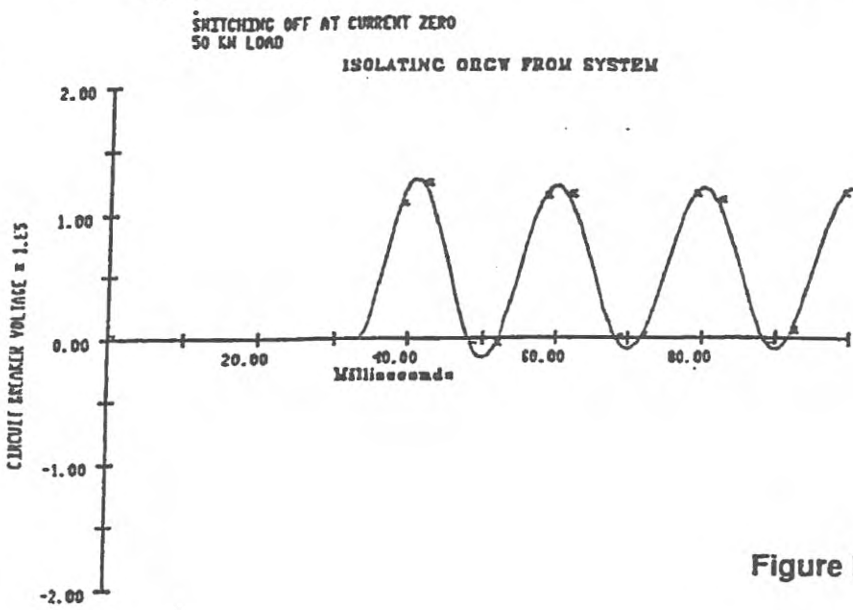


Figure D6

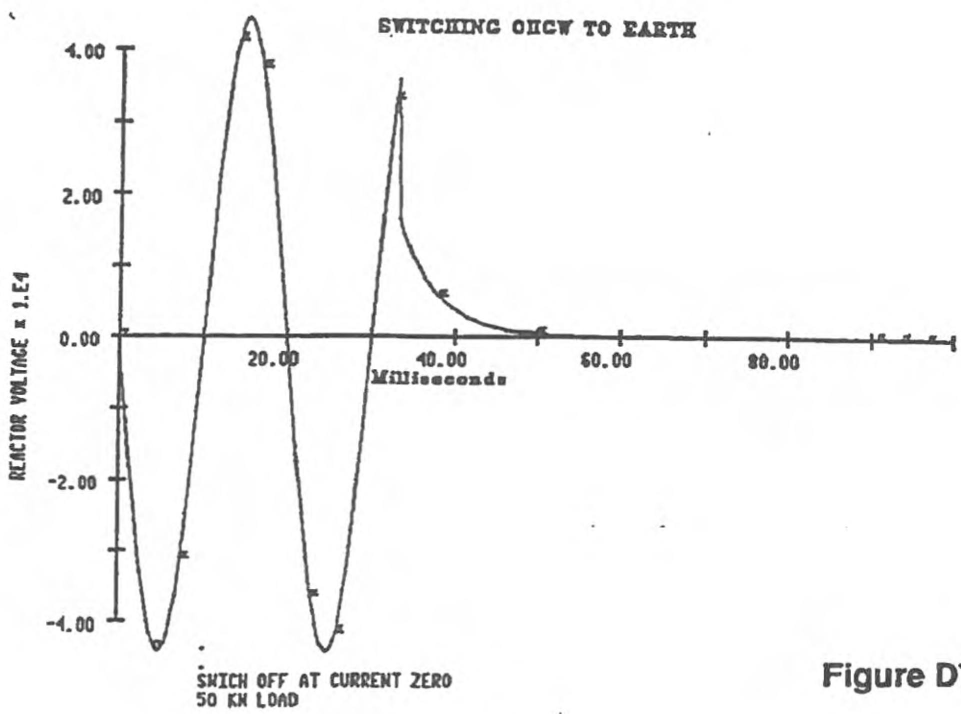


Figure D7

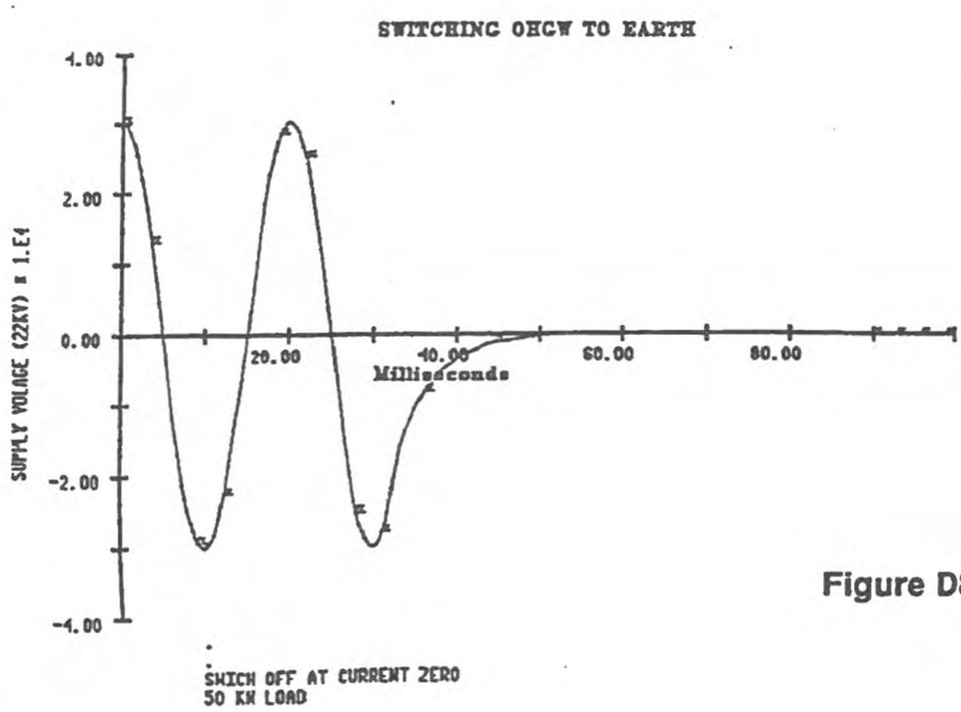


Figure D8

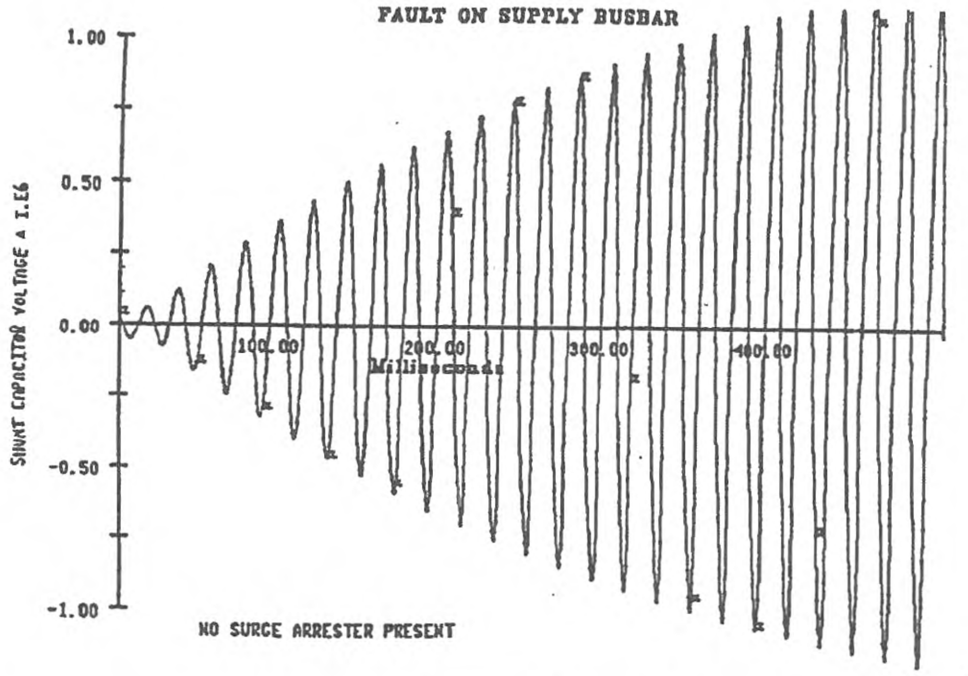


Figure D9

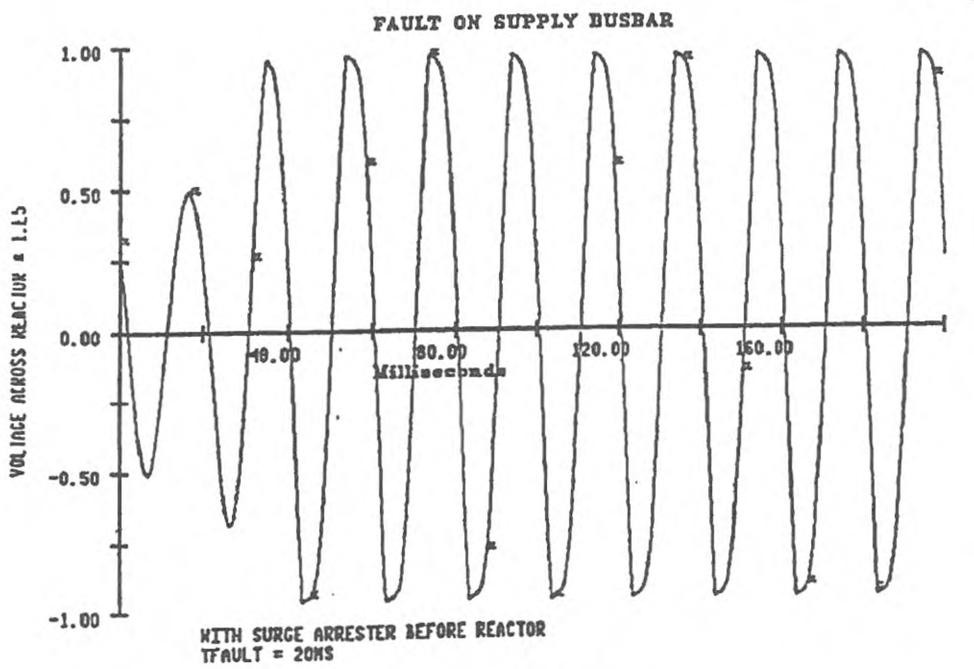


Figure D10

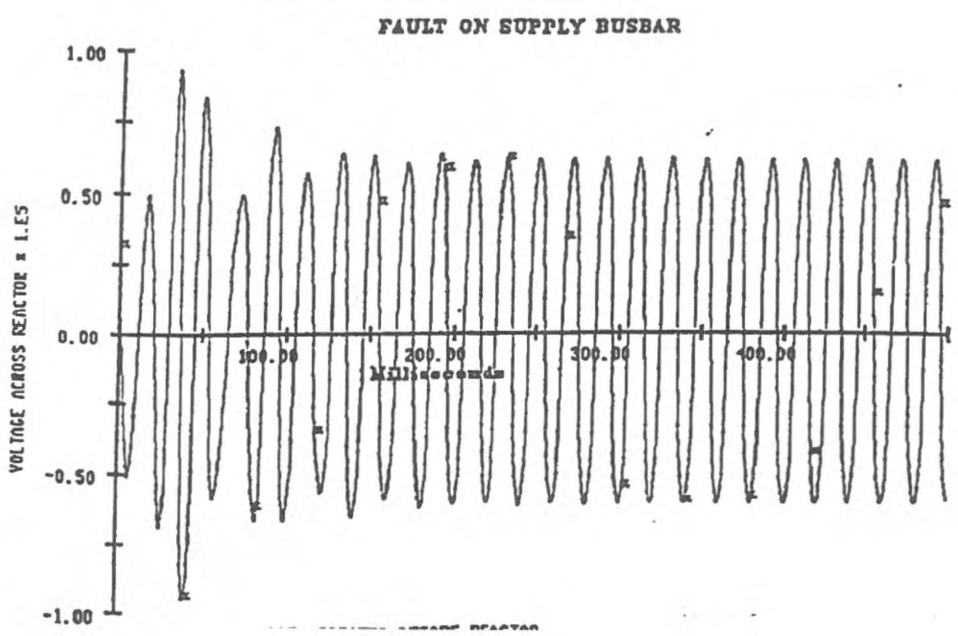


Figure D11

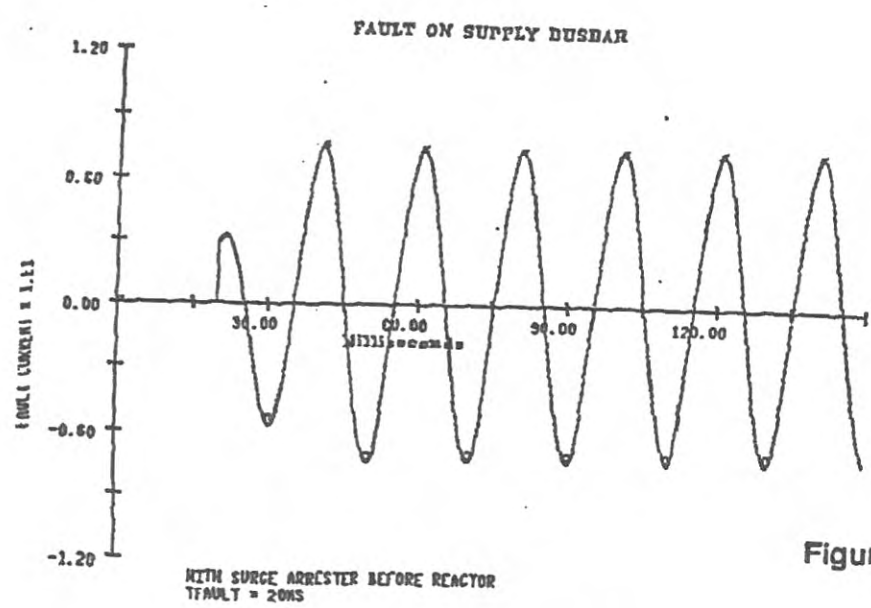


Figure D12

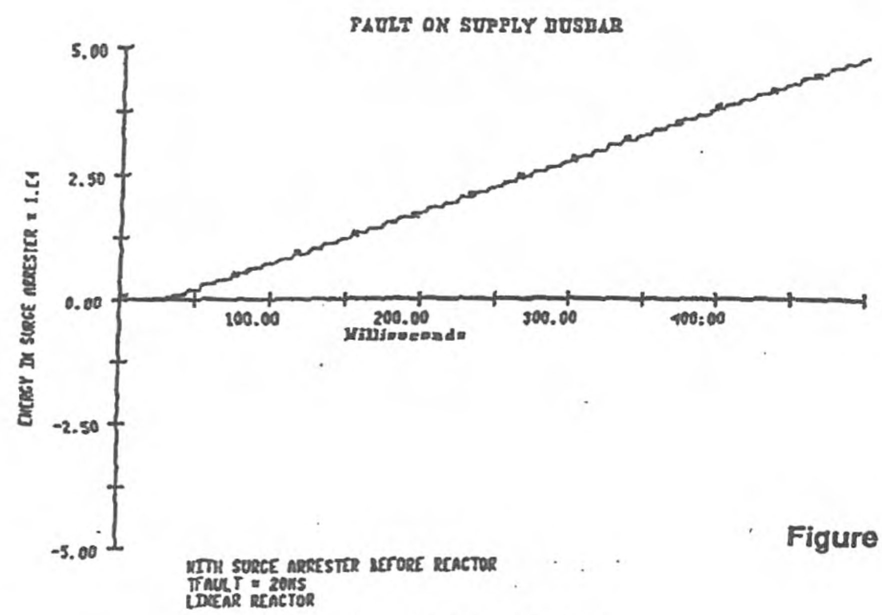


Figure D13

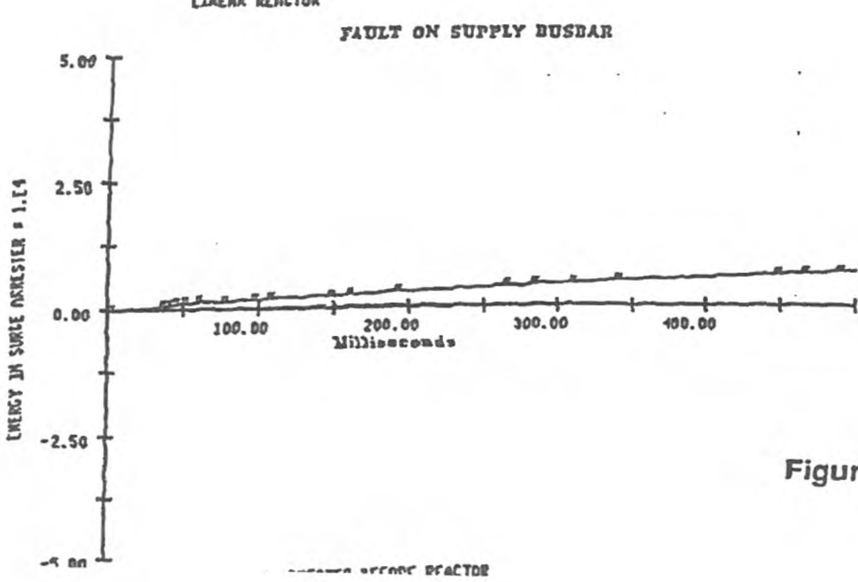


Figure D14

APPENDIX E MEASURED RESULTS

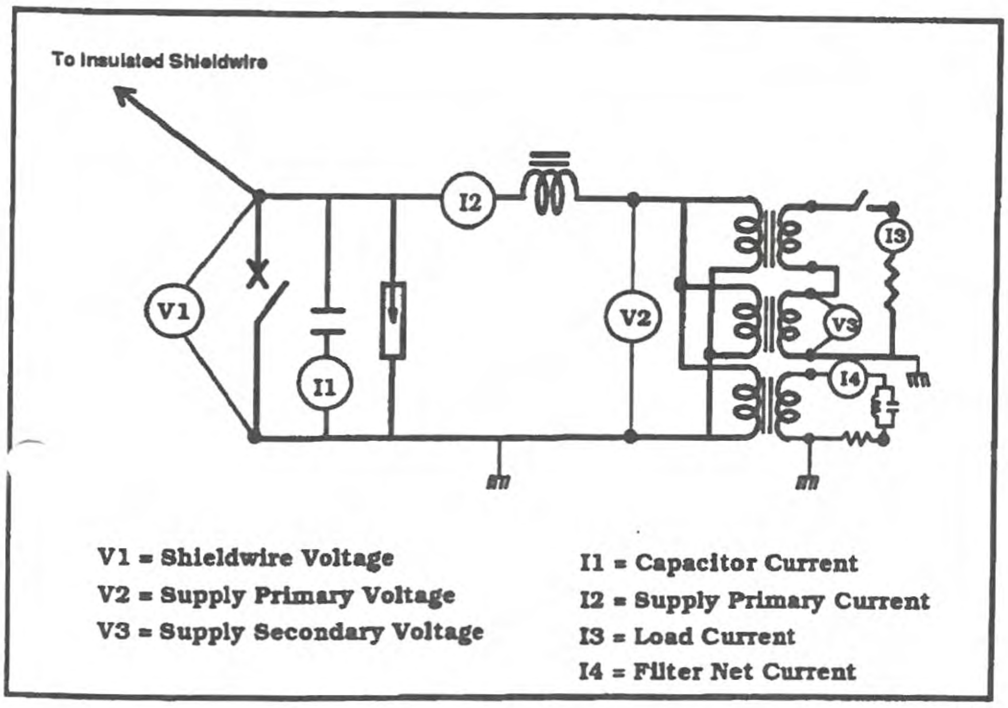


Figure E1 Diagram Showing Measurement Points

Measured Results of Voltage Regulation

Table E1 Rated Current Test on One Distribution Transformer

Turns Ratio: **95.2 : 1**

Load Current (A)	Supply Secondary Voltage (V)	P.U. Secondary Voltage	Supply Primary Voltage (kV)	P.U. Primary Voltage
0.0	125.5	1.00	11.98	1.00
8.5	124.5	0.99	11.97	1.00
17.1	123.4	0.98	11.94	1.00
25.7	122.5	0.98	11.92	0.99
33.9	121.8	0.97	11.92	0.99
41.9	120.9	0.96	11.91	0.99
50.8	119.6	0.95	11.80	0.98
58.5	119.1	0.95	11.81	0.99
65.9	118.0	0.94	11.81	0.99

Table E2 System Voltage Regulation

Supply Primary Current (A)	Supply Primary Voltage (kV)	P.U. Primary voltage	Output kVA
0.055	12.23	1.000	0.67
1.395	12.07	0.987	16.84

ENERGISE ENERGISE SYSTEM WITH NO FILTER

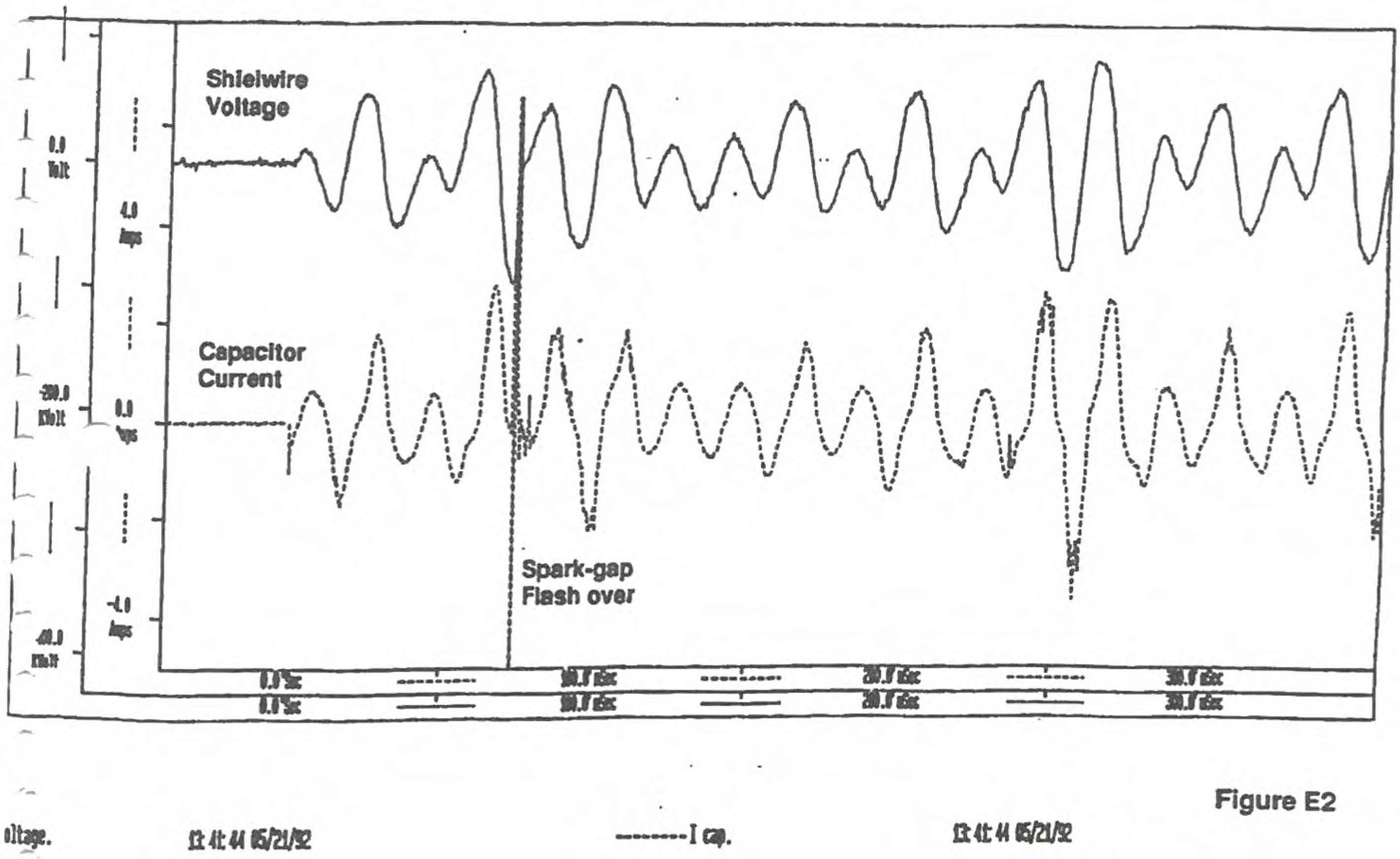


Figure E2

Energise TRF1&2 with 50% load on each Trfr.

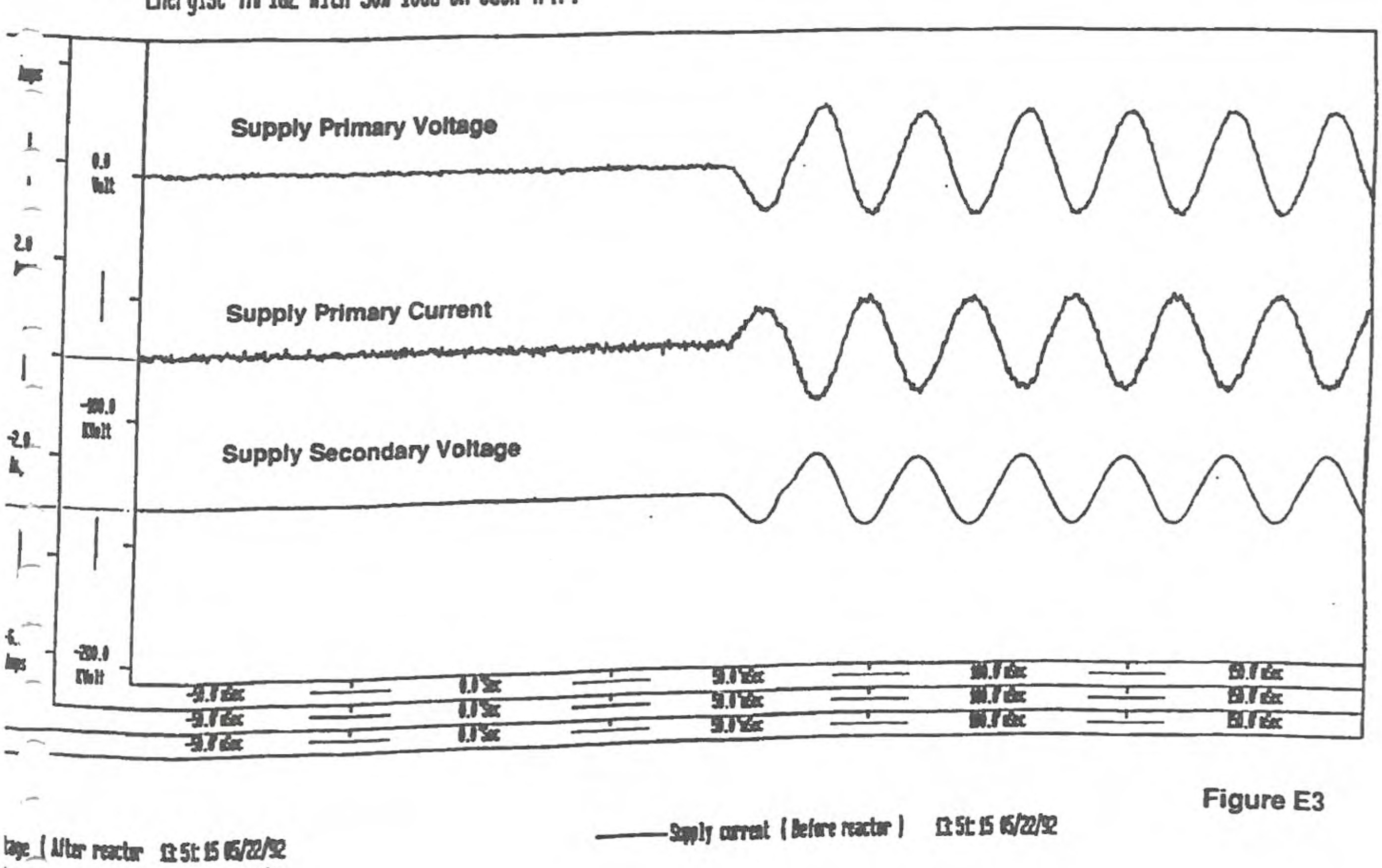


Figure E3

ENERGISE SYSTEM WITH NO FILTER

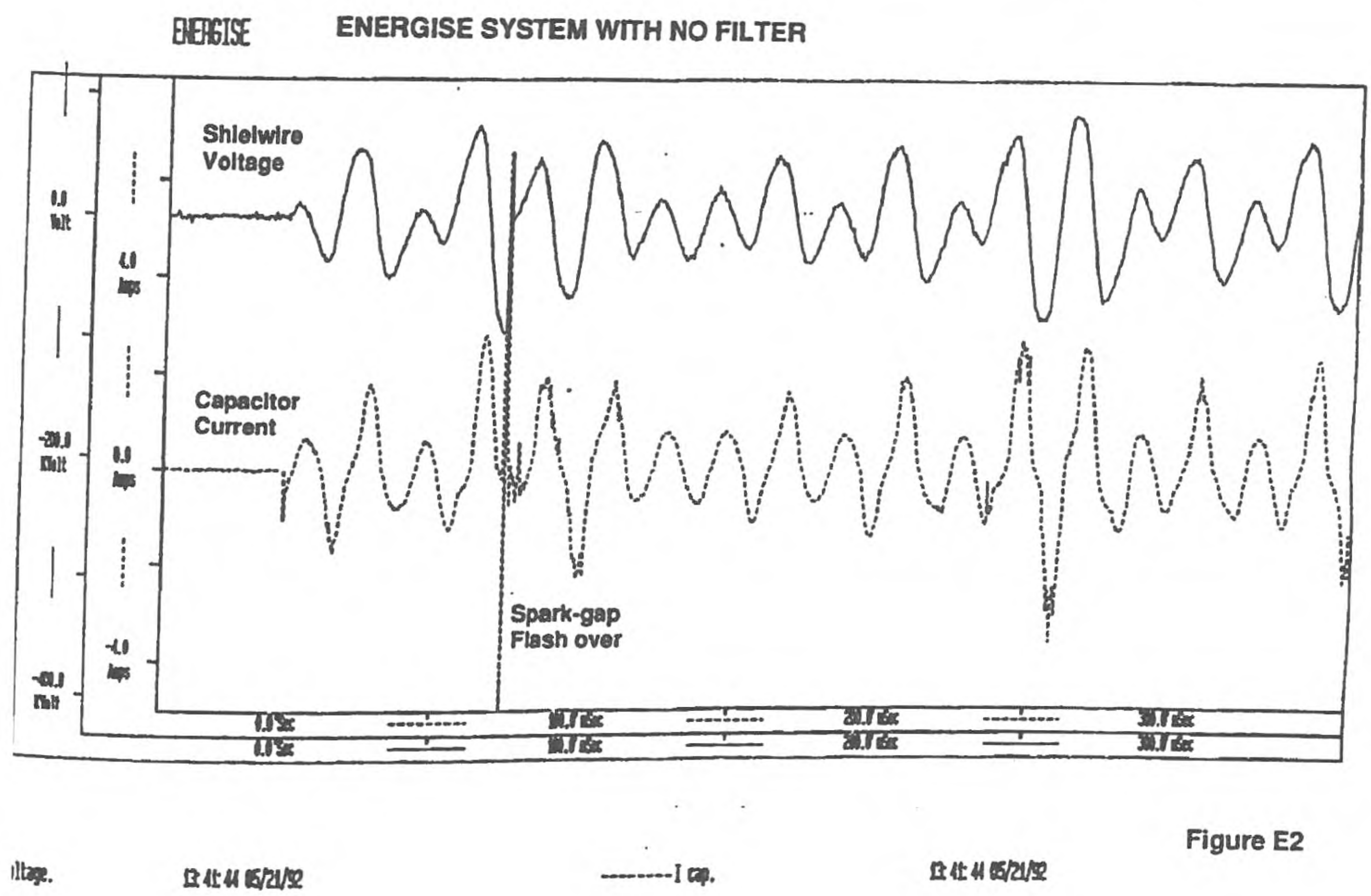


Figure E2

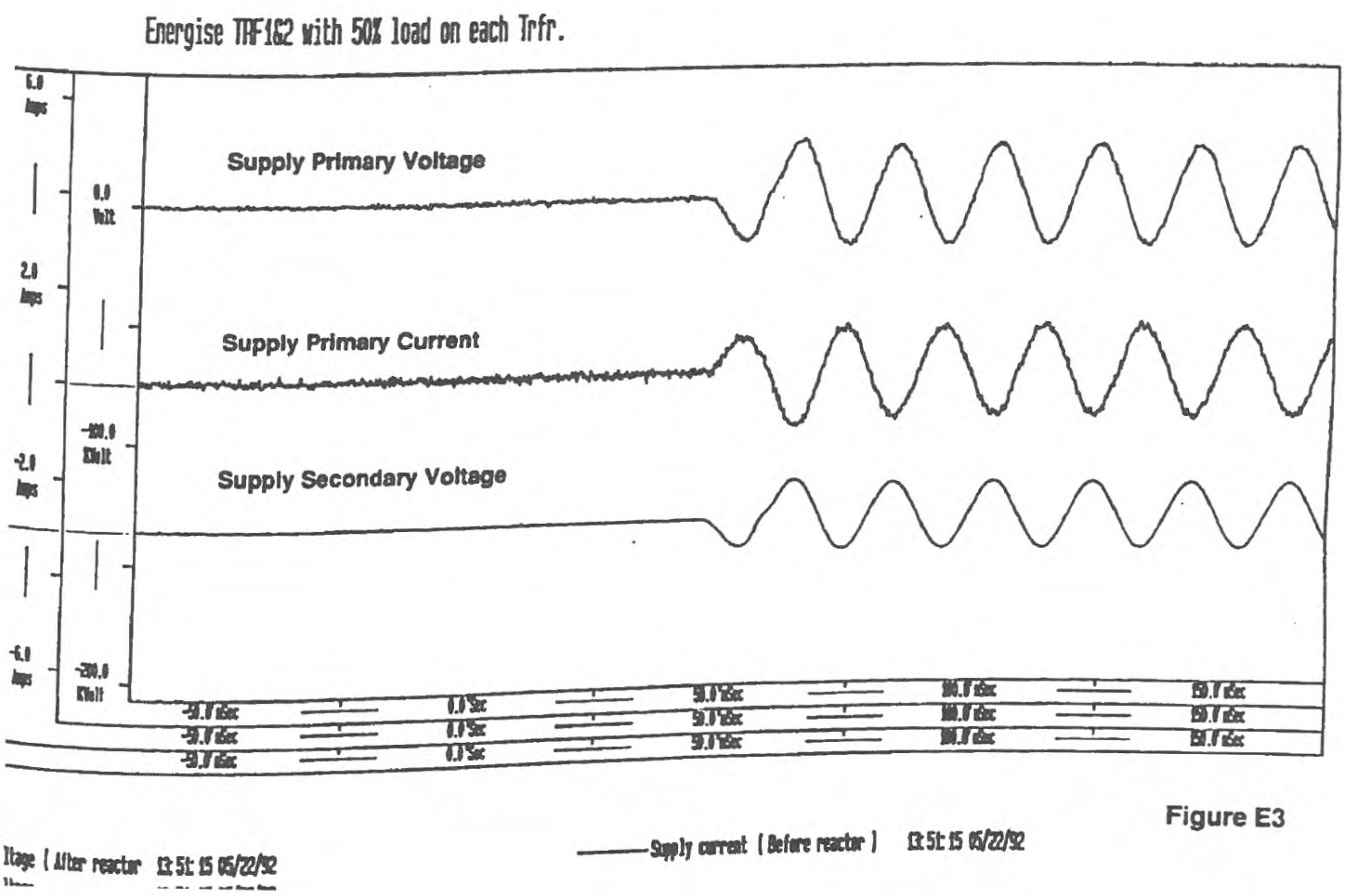


Figure E3

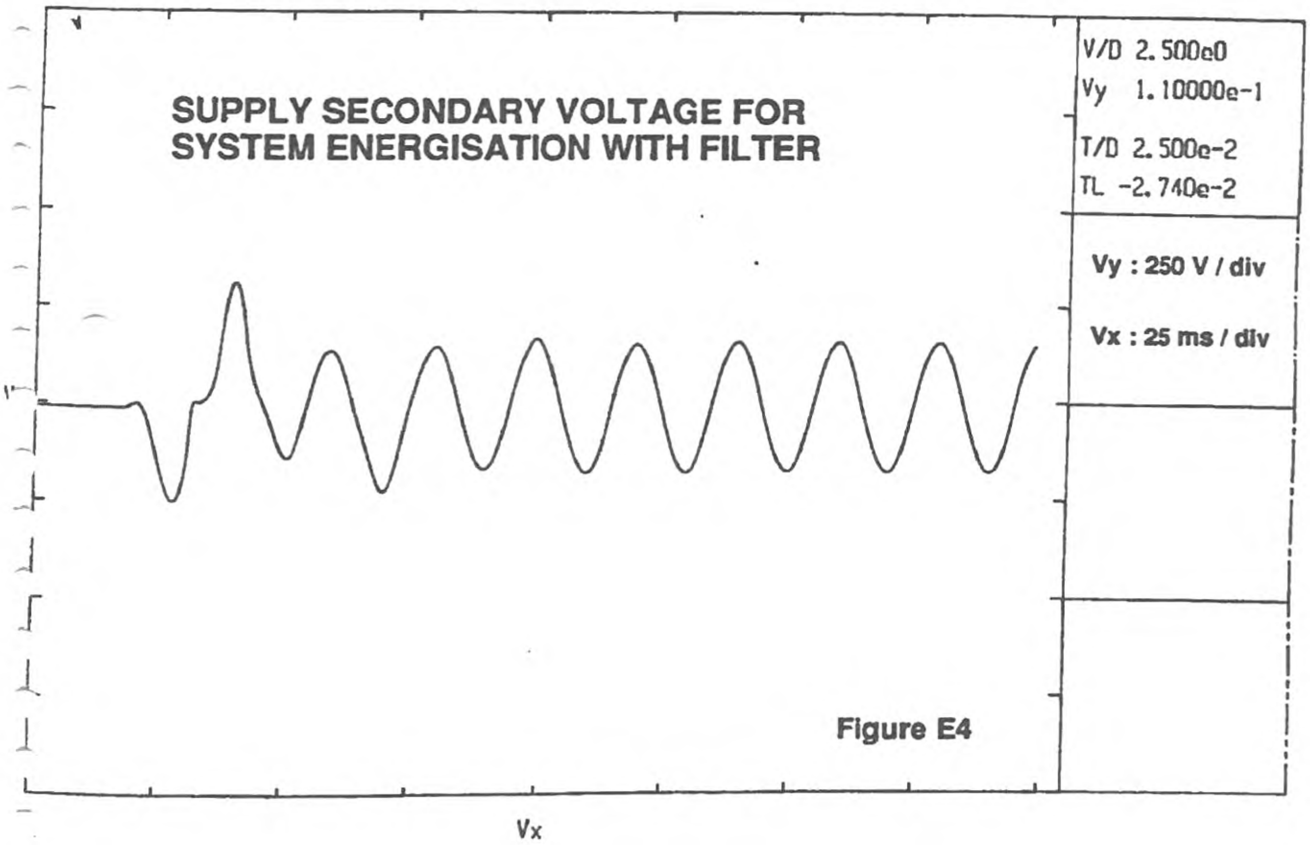


Figure E4

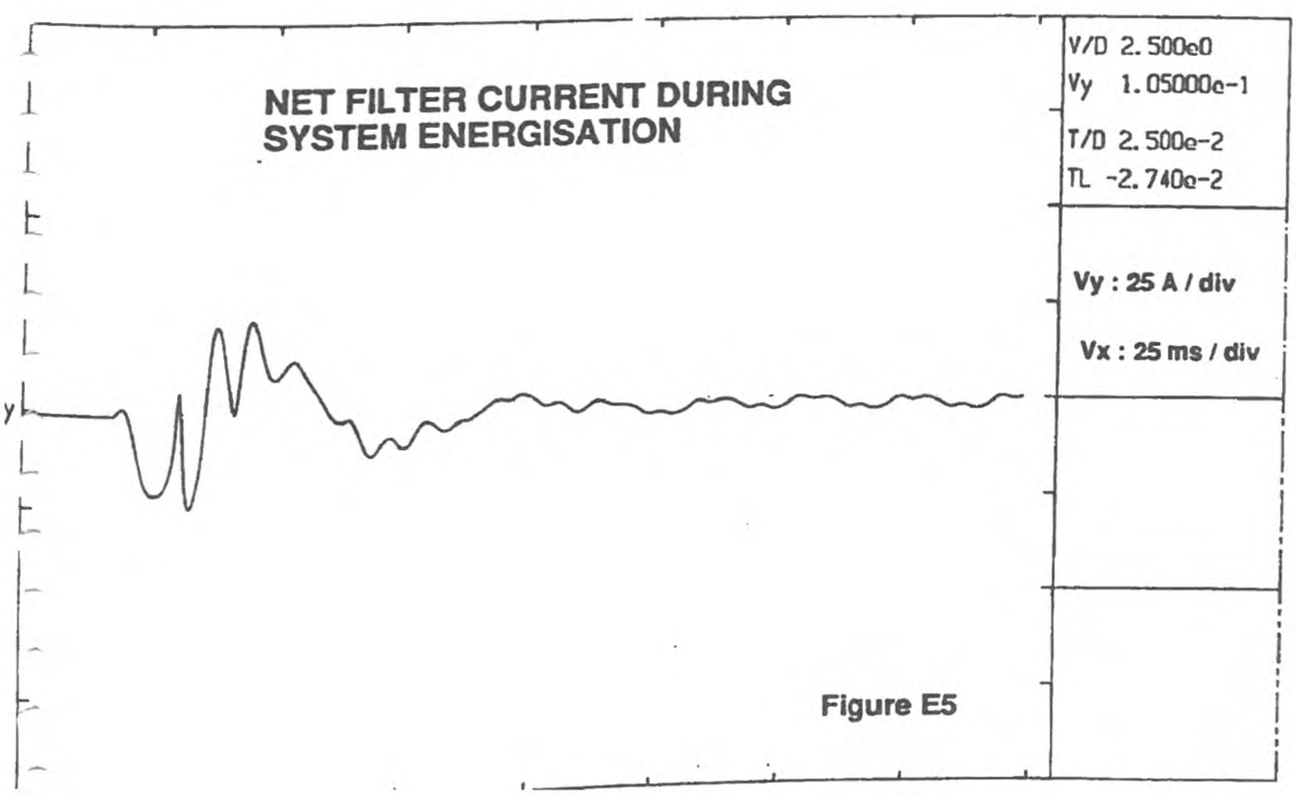


Figure E5

System 500

OC. FAULT SHORT CIRCUIT ON PRIMARY OUTPUT

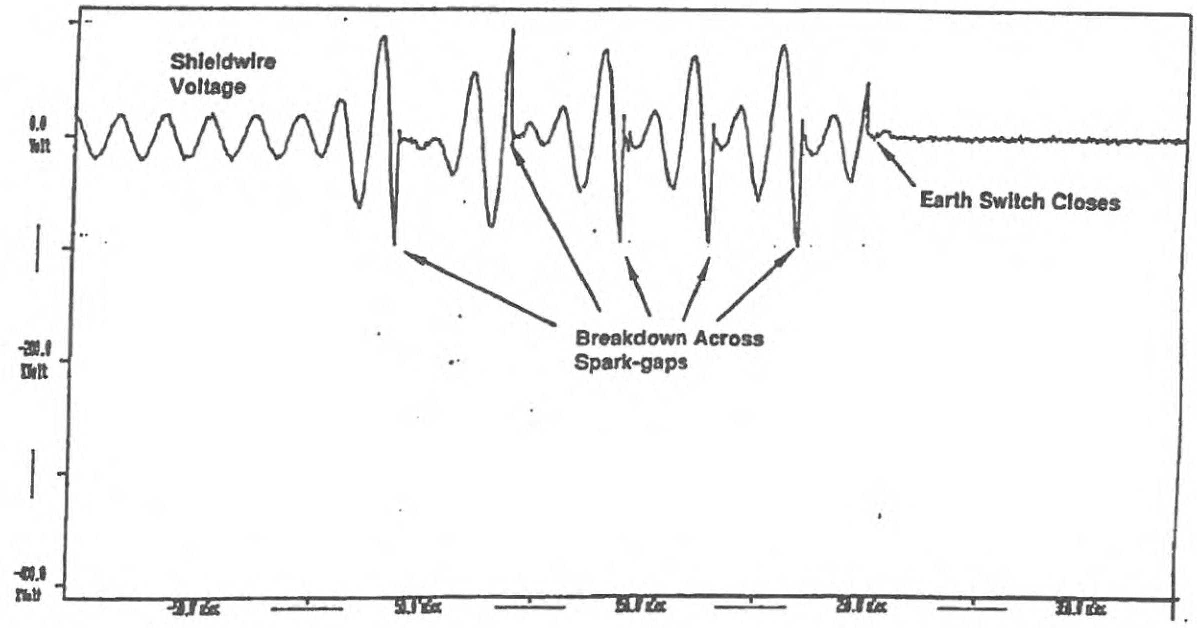
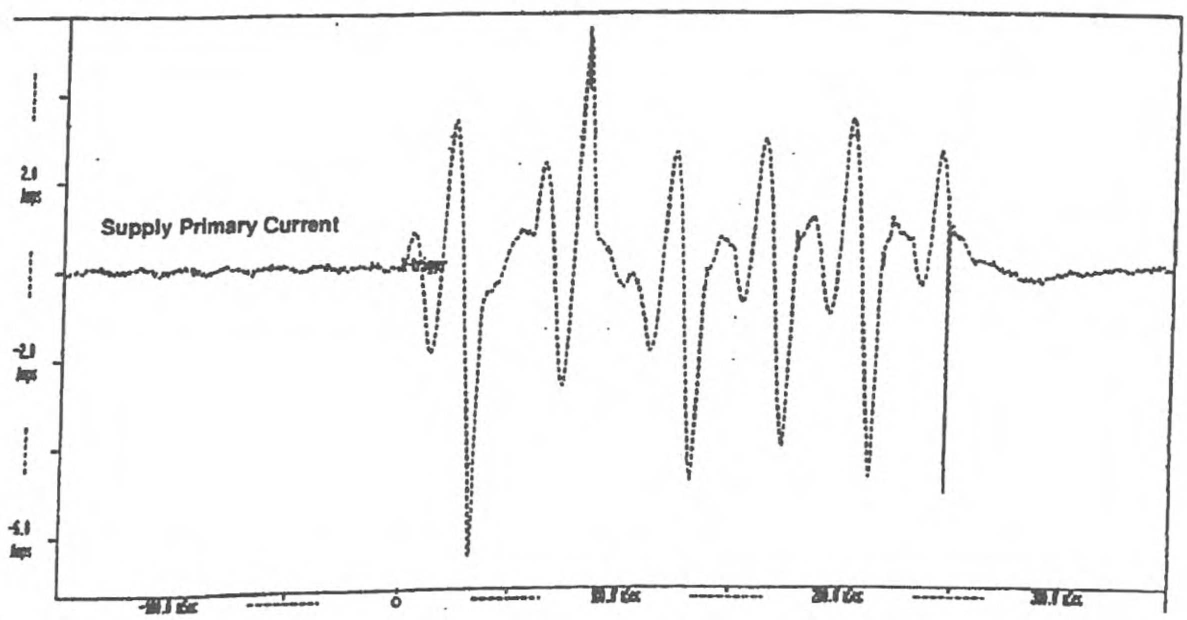


Figure E6

——Supply Voltage (before reactor) 15:26:11 05/25/92

System 500

OC. FAULT SHORT CIRCUIT ON PRIMARY OUTPUT



——Supply current (before reactor) 15:26:11 05/25/92

Figure E7

OC. FAULT SHORT CIRCUIT ON PRIMARY OUTPUT

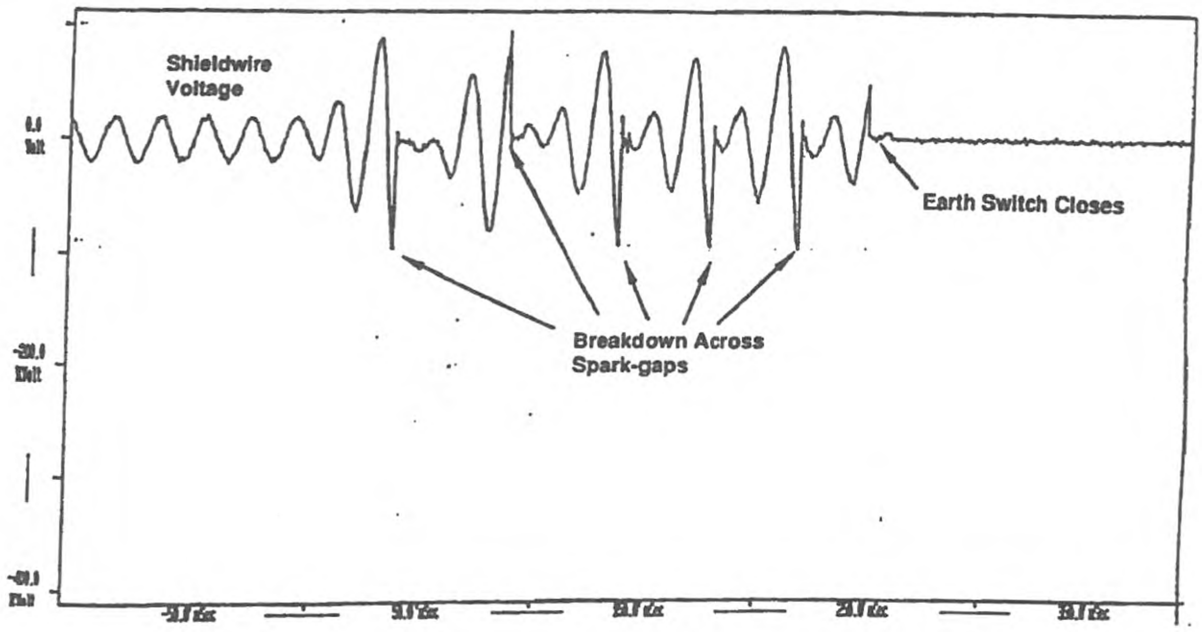
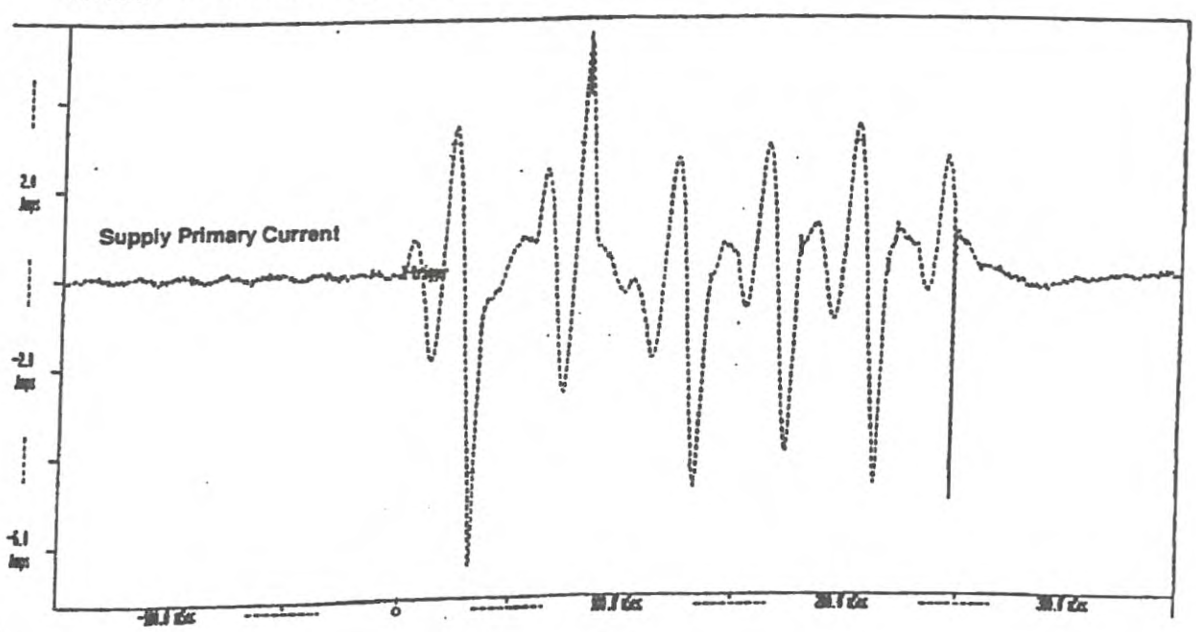


Figure E6

—— Supply Voltage (before reactor) 15:28:11 05/25/92

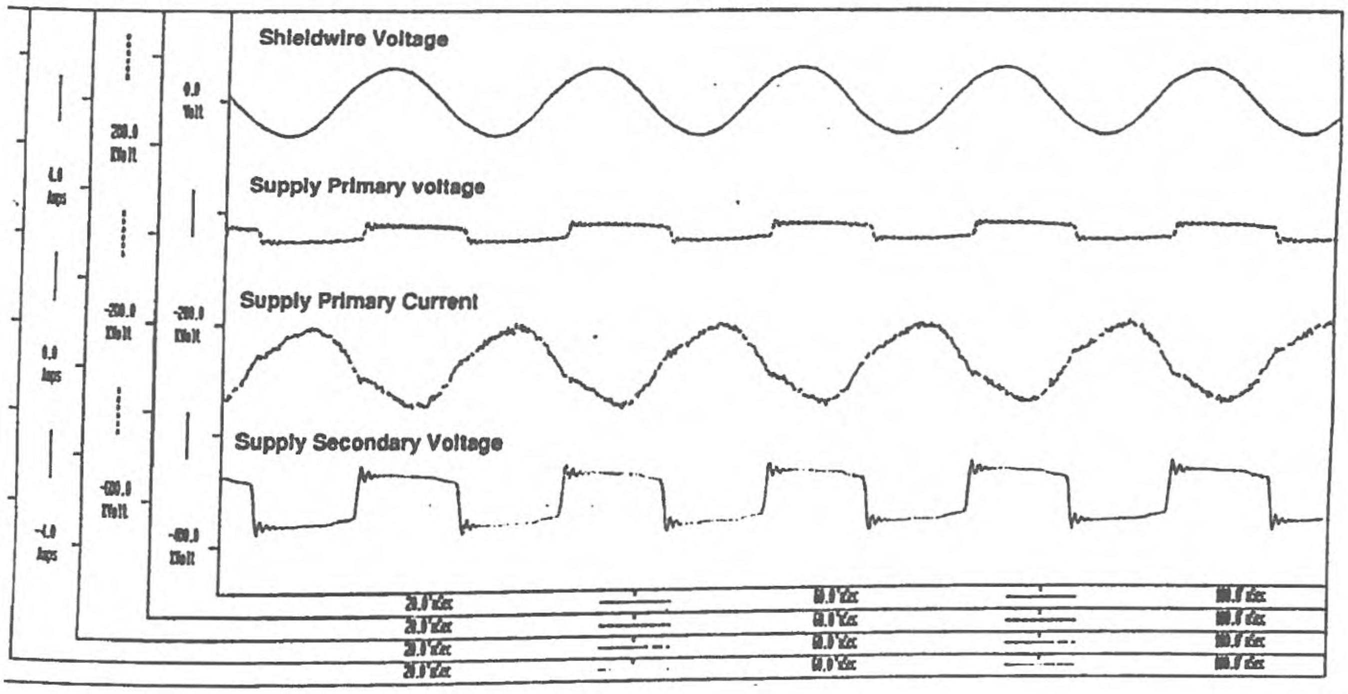
OC. FAULT SHORT CIRCUIT ON PRIMARY OUTPUT



—— Supply current (before reactor) 15:28:11 05/25/92

Figure E7

System 500 3 PHASE MOTOR STEADY STATE. 7.5 KW NON-LINEAR LOAD



Open cct. voltage. 15:11:03 05/26/92
Supply current (Before reactor) 15:11:03 05/26/92
——— Pri. supply voltage (After reactor 15:11:03 05/26/92
– ——— Sec. supply voltage 15:11:03 05/26/92

Figure E8

em 500 Trip load from TRF1. TRF2 no load. 4 kW LOAD REJECTION

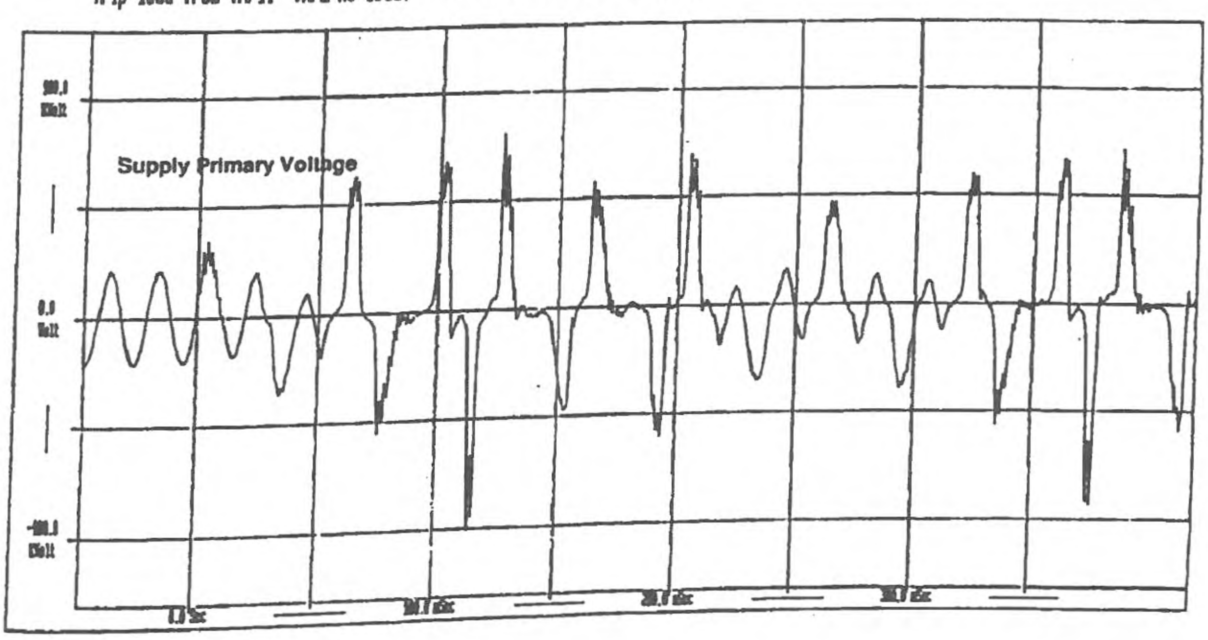


Figure E9

supply voltage (After reactor 14:03:10 05/22/92

Trip load TRF1. TRF2 no load. **4 kW LOAD REJECTION**

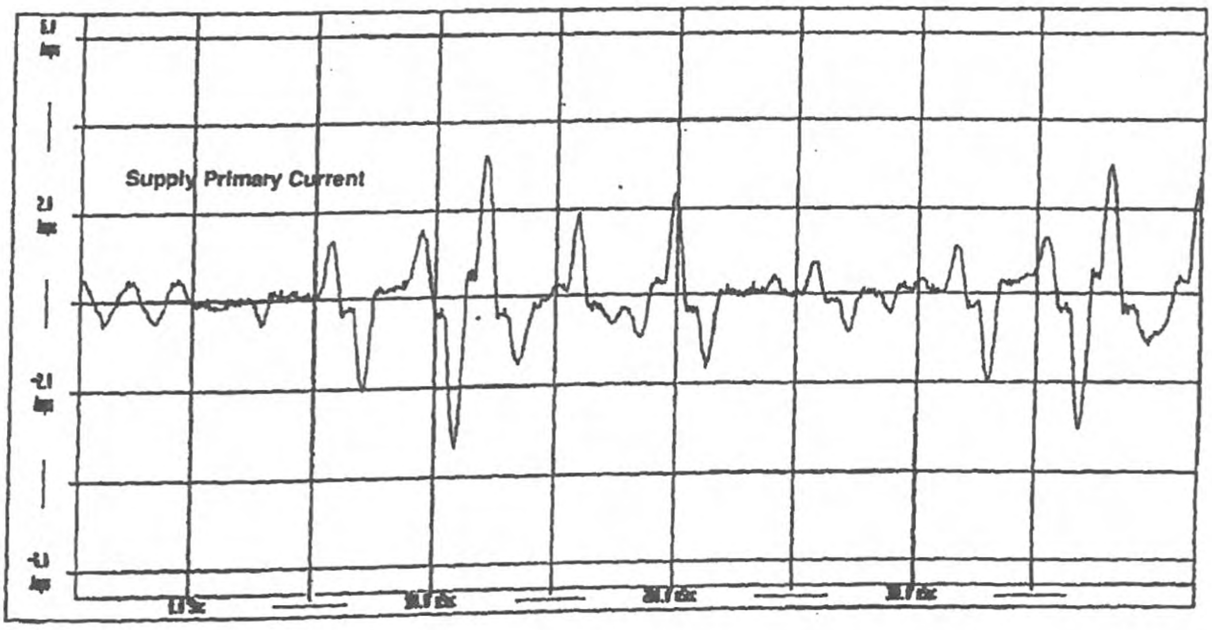


Figure E10

urrent (Before reactor)

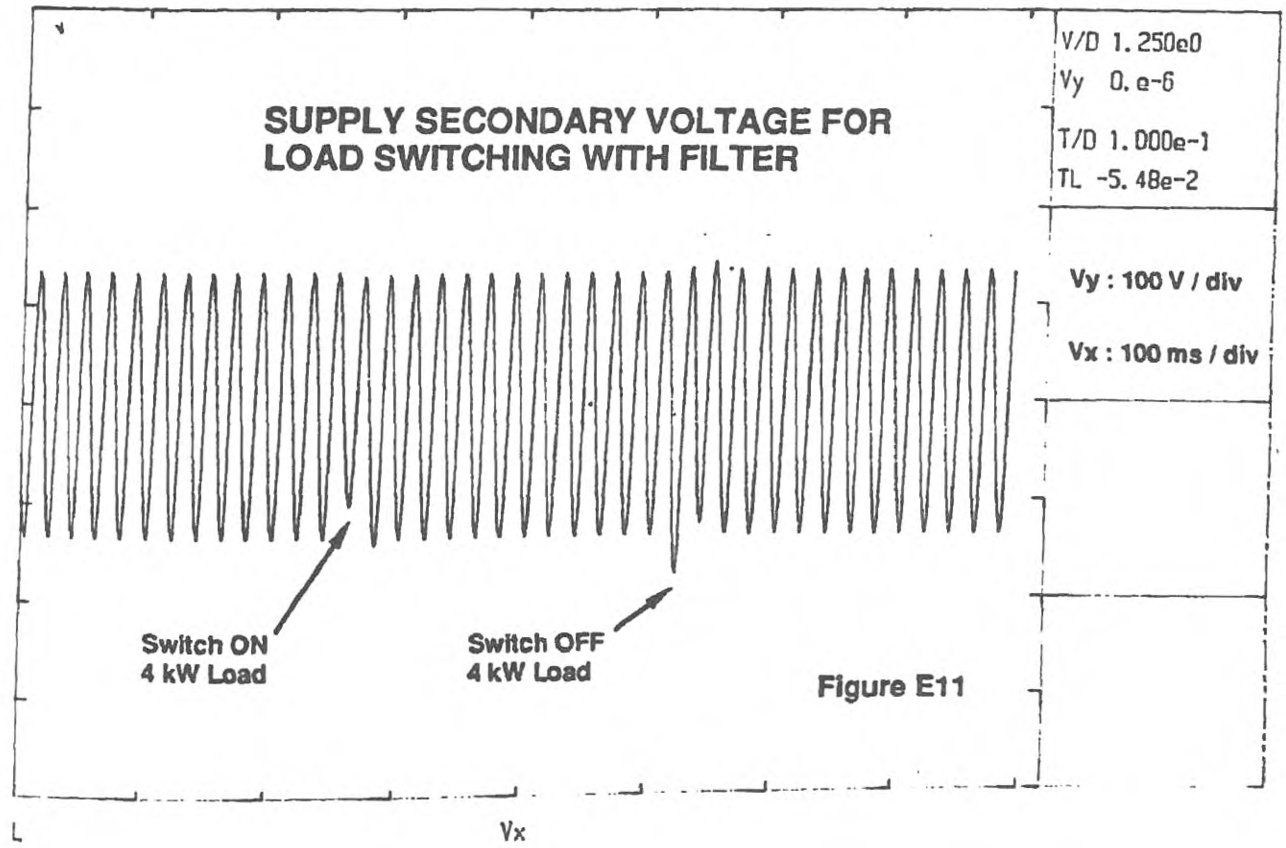


Figure E11

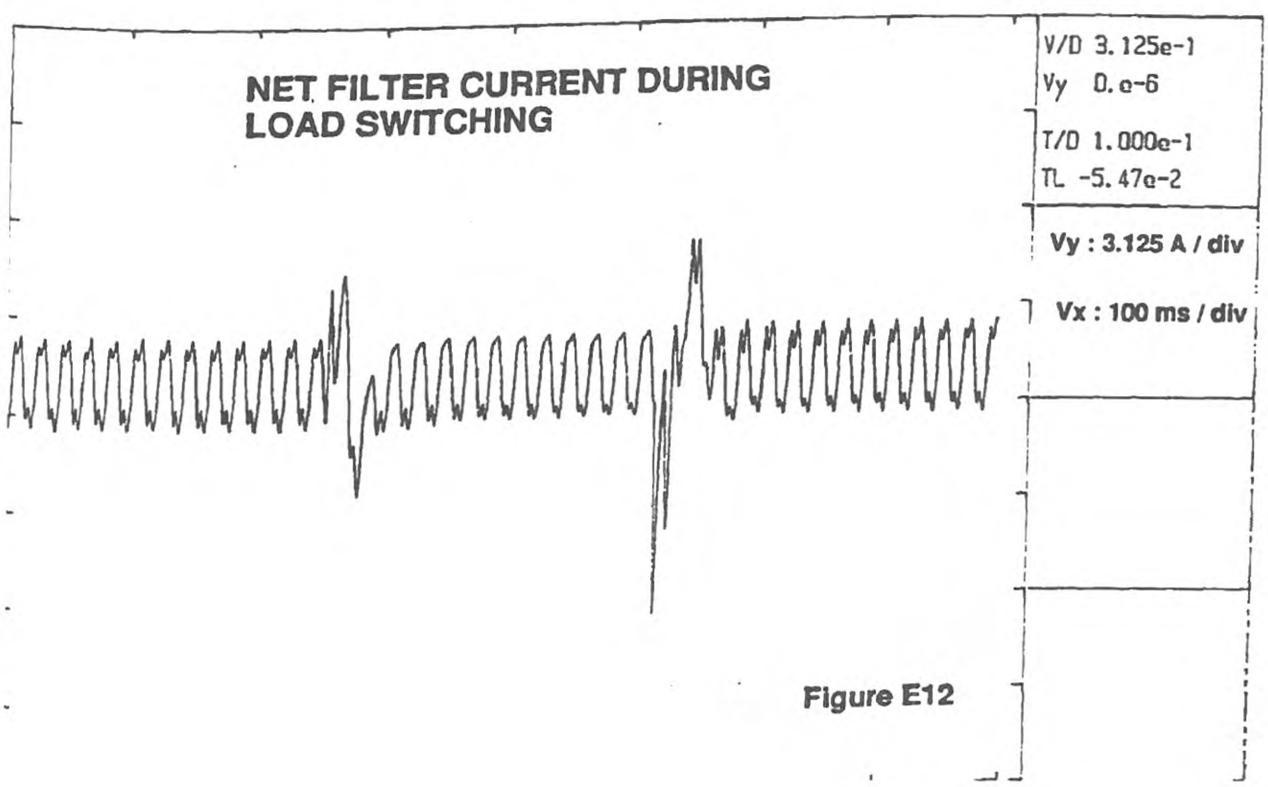
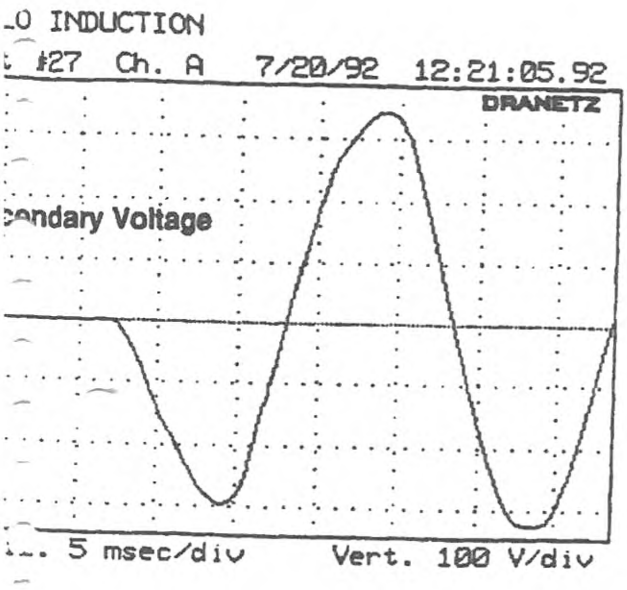


Figure E12



ure E13
ergise System with 4 kW Load
Opening Earth Switch

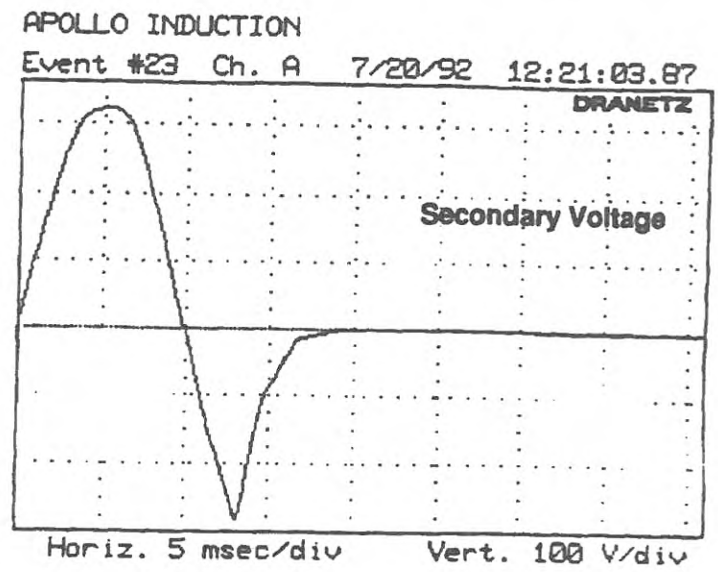
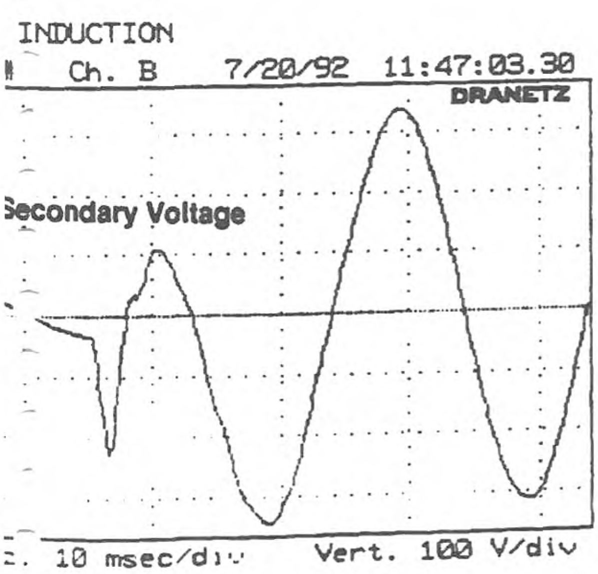


Figure E14
De-energise System
by Closing Earth Switch



e E15
ing switch Open,
ergise Transmission Line

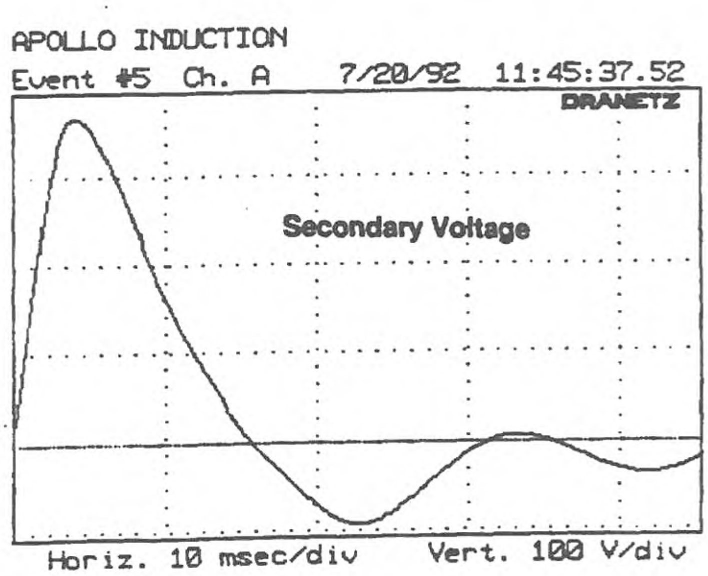


Figure E16
Earthing switch Open
De-energise Transmission Line

APPENDIX F SPECIFICATIONS USED FOR SYSTEM COMPONENTS

?/DB/SPEC1LS

E S K O M

SPECIFICATION

FOR

SPECIAL SINGLE PHASE SWITCH

CONTENTS PAGE

LS/DB/SPEC1LS

E S K O M

SPECIFICATION

FOR

SPECIAL SINGLE PHASE SWITCH

CONTENTS PAGE

1. *SCOPE*

This specification covers Eskom's requirement for a special single phase switch to be used in an experimental pilot scheme.

2. *ACTUATION*

The switch shall be actuated by means of a pneumatic system consisting of :

- 1 piston actuator
- 2 solenoid valves (12 V DC operation)
- 1 gas bottle
- 1 pressure regulator
- 1 "low pressure" switch
- all the necessary fittings

Manual operation shall also be possible by means of a "Link Stick".

3. *SWITCHING FUNCTION*

The switch shall be used to "earth" the source under a fault condition in the system and re-open when the fault has been cleared.

3.1 *Closing*

The switch shall be normally open when the system is in operation. When the "close" solenoid valve is actuated, the switch shall close completely within in 0,5 seconds of receiving the signal. This may be achieved by the use of a toggle and spring arrangement. The switch blade will be at ground potential and will close onto the contact which will be at 70 kV Rms (worst case).

3.2 *Opening*

When the "open" solenoid valve is actuated the switch shall open completely within 1 second. The switch shall be capable of breaking 1,5 Amperes at a voltage of 22 kV without drawing an arc. This may be achieved by means of a spring-steel contact.

4. INSULATION LEVELS

4.1 Earthing Side

The switch blade shall pivot on the earthy side of the switch. This shall still however be insulated by means of the standard 22 kV insulators.

4.2 Source Side

The source side contact shall be insulated by means of 2 x 22 kV insulators in series.

5. MOUNTING

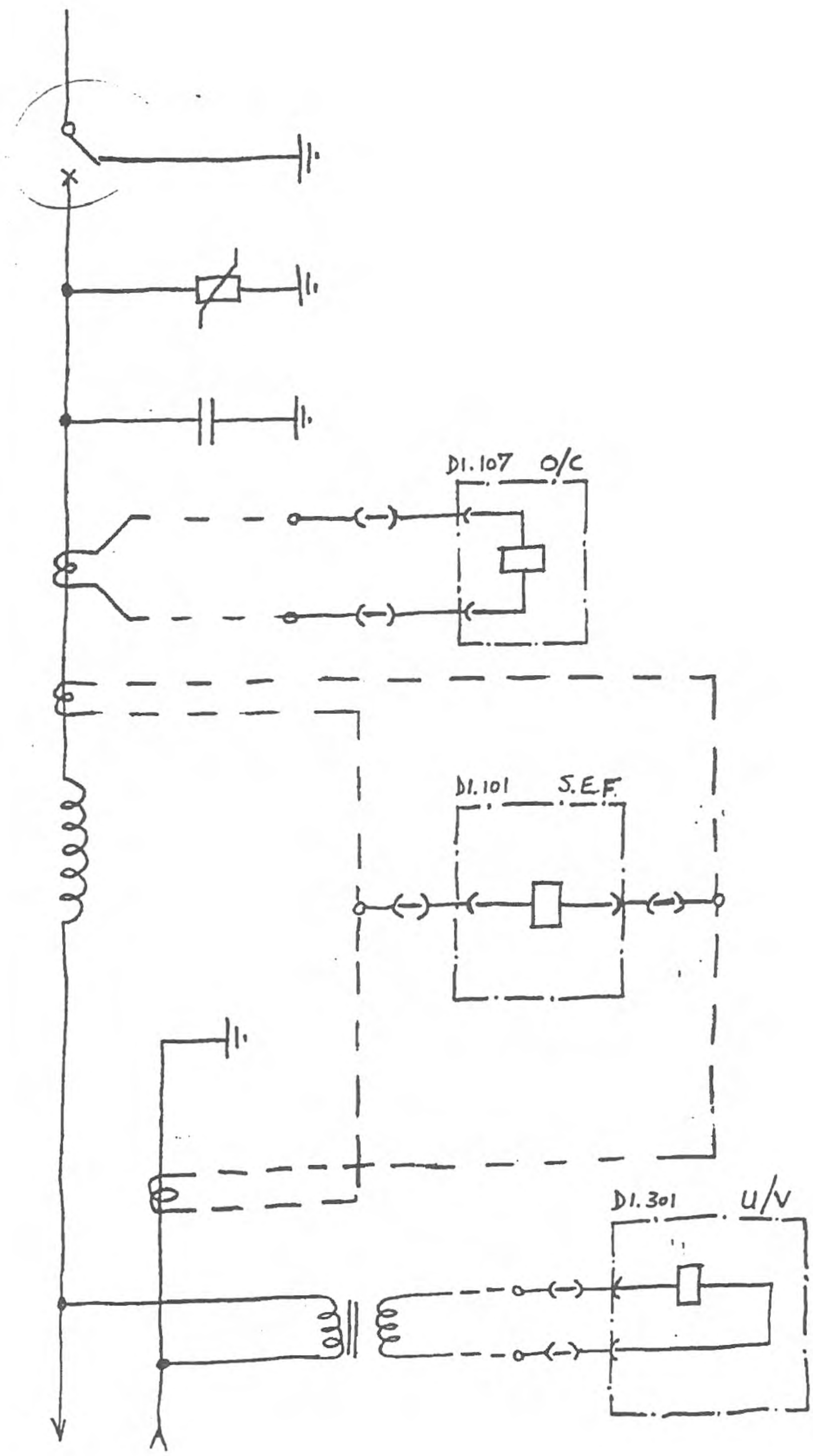
The entire switch mechanism shall be pole-mounted 7 m above the ground. The gas cylinder with solenoid valves etc. shall be enclosed in a weatherproof steel cabinet at the foot of the pole.

6. DELIVERY AND COMMISSIONING

The switchgear shall be delivered to the site (just outside Apollo Substation) and erected. Commissioning shall be performed with Eskom's project leader present.

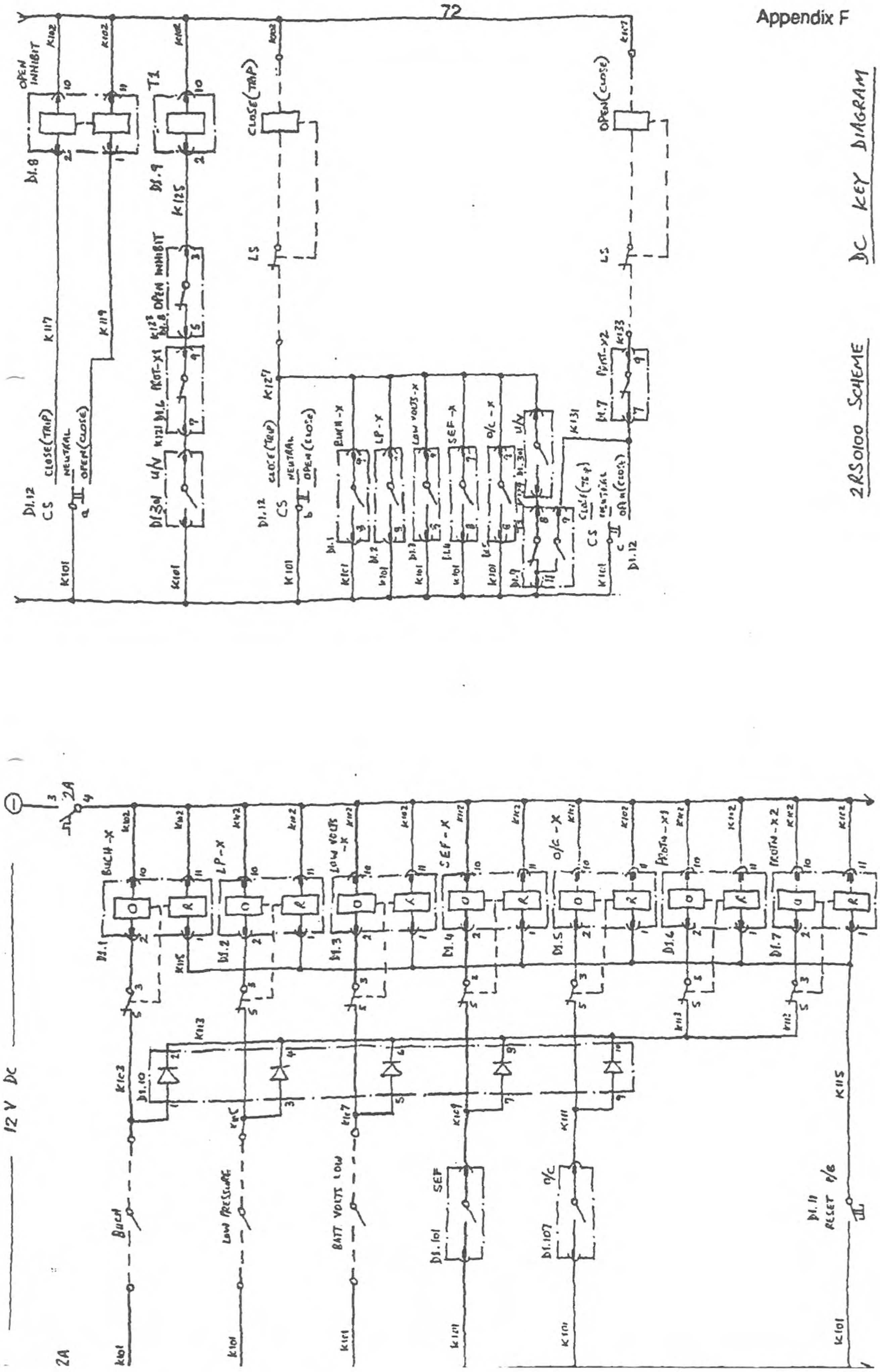
SUMMARY OF SPECIFICATION

DESCRIPTION	ESKOM REQUIREMENT	MANUFACTURER SUPPLIES
1. PNEUMATIC SYSTEM		
1.1 Pneumatic piston diameter (mm)	-	
1.2 Solenoid valve input signal (Vdc)	12	
1.3 Gas bottle size (l)	-	
1.4 Pressure regulated to (kPa)		
1.5 "Low pressure" switch on pressure gauge	YES	
2. MANUAL OPERATION	LINK STICK	
3. SWITCHING FUNCTION		
3.1 Closing		
3.1.1 Closing time (signal - fully closed) (ms)	500	
3.1.2 Closing voltage (kV)	70 Rms	
3.1.3 Peak current on closing (A)	300	
3.2 Opening		
3.2.1 Opening time (signal - fully open) (ms)	1000	
3.2.2 Opening voltage (kV)	22 Rms	
3.2.3 Current breaking capability (A)	1,5	
4. INSULATION LEVELS		
4.1 Earth side (1 min withstand wet) (kV)	-	
4.2 Source side (1 min withstand wet) (kV)	44 kV	
5. DELIVERY, ERECTION & COMMISSIONING AT SITE	YES	



2RS0100 SCHEME

AC KEY DIAGRAM


2RS0100 SCHEME
DC KEY DIAGRAM
12 V DC
OPEN INHIBIT
CLOSE (TRIP)
OPEN (CLOSE)
NEUTRAL
BUCH-X
LP-X
LOW VOLTS -X
SEF-X
O/C-X
PROTN-X1
PROTN-X2
BUCH
LOW PRESSURE
BATT VOLTS LOW
SEF
O/C
RESET O/B

JS/DB/SPEC1

SPECIFICATION FOR
LOW VOLTAGE FILTER

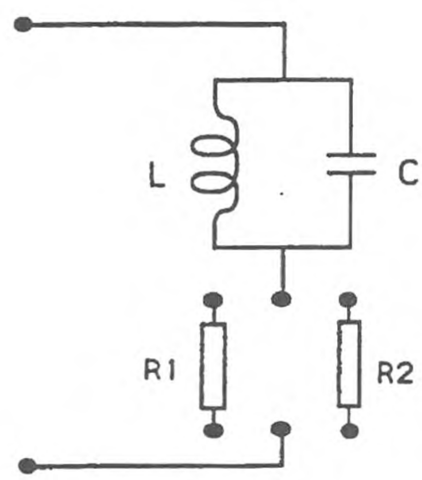
CONTENTS

- 1 -

1. *SCOPE*

This Specification is specific to a parallel resonant filter required for experimental purposes.

2. *SCHEMATIC DIAGRAM*



3. *FUNCTIONAL DESCRIPTION*

The reactor and capacitor must be resonant at 50 Hz (ie. $|X_l| = -|X_c|$ at 50 Hz). The filter will be used to damp out transients while not absorbing much energy during steady state 50 Hz conditions.

4. *RATINGS*

Detailed ratings can be found in the Schedule of technical requirements. The ratings of each element are handled separately.

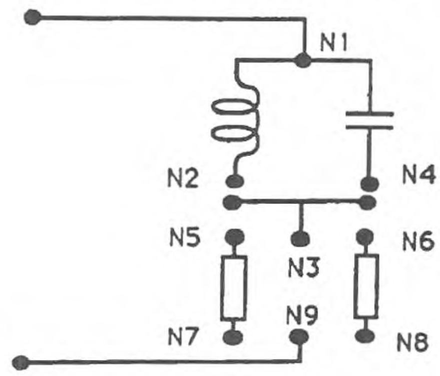
5. *CONSTRUCTIONAL DETAILS*

5.1 General

The filter will be used indoors. All the components must be mounted in one standalone sheet metal box. Connection terminals must be located outside the box to allow for measuring and testing of voltages and currents. The box must have handles to allow carrying of the filter by one or two persons (if possible).

5.2 Connections and Terminals

The following nodes must be accessible for measuring purposes :



Each node must be labelled for reference to the rating plate.

5.3 Diagram and Rating Plate

The rating plate must show the values of components as well as the node number related to each component. The parameters to be shown on the rating plate are indicated in the Schedule of technical requirements.

6. *TESTING*

The following tests must be performed and certificated :

4.1 Reactor Magnetization Curve

The supplier must provide a V-I curve for the reactor showing the knee-point voltage (if applicable) at 50 Hz.

6.2 Tuning of Capacitor and Reactor

The supplier must provide a test to show that the capacitor and reactor are tuned to within the stipulated tolerance up to 1.2 pu of the continuous operating voltage.

This may be done by measuring the current which flows from the voltage source through the parallel combination of the reactor and capacitor.

SCHEDULE OF TECHNICAL REQUIREMENTS		ESKOM REQUIREMENTS	SUPPLIER GUARANTEES
1. TUNING FREQUENCY	[Hz]	50	
- Maximum unbalance current at 1.2 pu of rated voltage	[A Rms]	1	
2. REACTOR DETAILS			
(a) Maximum continuous operating voltage (shunt)	[V Rms]	120 *	
(b) Continuous operating current	[A Rms]	19 *	
(c) Maximum operating temperature	[^{o}C]	75	
(d) Minimum X/R ratio at operating temperature		30 *	
(e) Inductance	[mH]	25,25*	
(f) Air Core / Iron core			
(g) Kneepoint voltage (minimum)	[V Rms]	150	
3. CAPACITOR DETAILS			
(a) Maximum continuous operating voltage	[V Rms]	120 *	
(b) 3 Second temporary over-voltage	[V Rms]	240	
(c) Capacitance	[µF]	400 *	
4. RESISTOR DETAILS			
(a) Quantity of resistors		2	
(b) Resistance	[OHM]	5	
(c) Continuous power dissipation capability	[W]	500 *	
5. INSULATION FOR TOTAL INSTALLATION			
(a) 50 Hz 1 min. withstand	[V Rms]	1000	
(b) Impulse withstand (1,2/50 µs)	[V Peak]	2000	

LS/DB/SPEC

E S K O M

SPECIFICATION

FOR

SPECIAL CLASS-X CURRENT TRANSFORMER

1. *SCOPE*

This specification covers Eskom's requirements for one special Class-X Current Transformer suitable for outdoor use.

2. *MOUNTING*

The CT should be suitable for pole mounting and should be supplied with all the necessary brackets.

3. *TERMINAL BUSHINGS*

The primary coil should have one termination on the top and the other on the bottom of the CT. The secondary winding should have its terminations on the bottom of the CT.

4. *DELIVERY*

The CT shall be delivered complete with fittings and brackets by no later than 28 FEBRUARY 1992.

TECHNICAL DETAILS OF EQUIPMENT

DESCRIPTION	REQUIRED BY ESKOM.	GUARANTEED BY MANUFACTURER
Turns Ratio	1/2.3	
Class	X	
Minimum Secondary Knee-point Voltage	60 Volts	
Maximum Secondary Magnetizing Current	120 mA	
Maximum Secondary Resistance	1.0 Ω	
Maximum Continuous Primary Current	2.5 A	
Short Time Current (3 sec)	10 A	
Primary Winding Insulation level (50 Hz)	6.6 kV	
Insulation Medium	(paper + Oil) / resin	

LS/DB/SPEC2LS

E S K O M

SPECIFICATION

FOR SPECIAL SINGLE PHASE SHUNT CAPACITOR BANK

1. *SCOPE*

This Specification covers Eskom's requirements for one Single Phase Capacitor Bank suitable for outdoor use. The capacitor is to be used in the shieldwire induction prototype project.

2. *EXTENT OF CONTRACT*

The supply of the following :

- Capacitors housed in suitable capacitor cans.
- Bushings with the specified ratings.
- Base plate for mounting capacitor cans.
- Post insulator for mounting the capacitor bank.
- All the necessary hardware required for assembly and erection of the capacitor bank on a suitable steel I-beam.
- Solid (inter-capacitor can) terminal connector.
- Suitable connector from one terminal to earth.
- Suitable connector from "mid-point" terminal to base plate.
- One conductor-terminal connector.
- A name plate showing the capacitance value between each terminal and showing the equivalent shunt capacitance for the alternative interconnection arrangements.

3. *DELIVERY AND ERECTION*

The capacitor bank shall be complete for delivery by no later than 28 February 1992.

The supplier shall quote separately for the erection of the capacitor bank. (Including the I-beam and concrete foundation).

4. *DESIGN DETAILS*

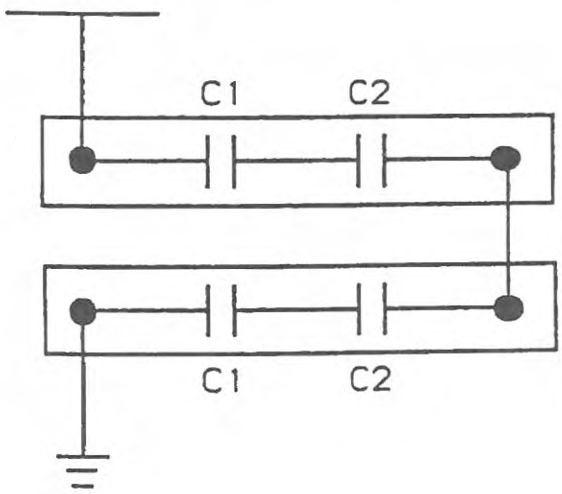
See attached diagram.

The capacitor bank shall consist of two identical capacitor cans. Each capacitor can shall contain two capacitors who's values are shown on the accompanying diagram and in Schedule A. The two capacitor cans shall be connected in series and there shall be three connection terminals on each capacitor can. The two capacitor cans shall be mounted on a base plate which shall form the electrical "mid-point" of the bank. The base plate shall be supported by a post insulator which will be mounted on a steel I-beam 2 m above ground. There shall be 3 alternative connection arrangements (as shown in the attached diagram) giving 3 different effective capacitance values.

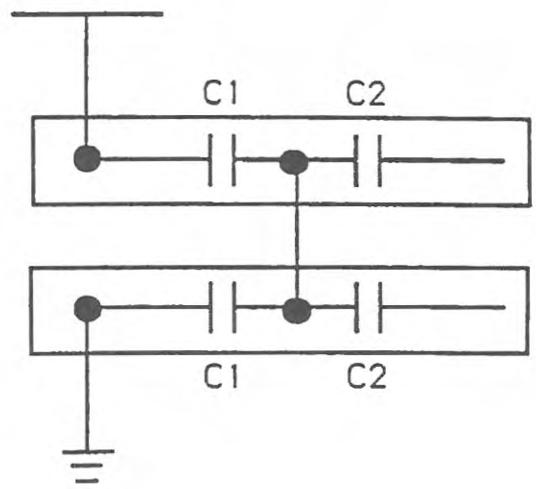
Voltage and current ratings are given in Schedule A.

Schematic Diagram of Capacitor Bank

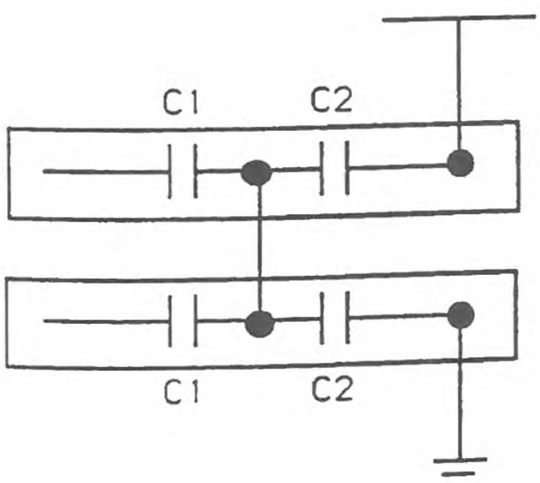
Alternative 1



Alternative 2



Alternative 3



Where:

C1 = 220nF

C2 = 300nF

SUMMARY OF SPECIFICATION

TECHNICAL DESCRIPTION		SCHEDULE A ESKOM REQUIREMENTS	SCHEDULE B SUPPLIER GUARANTEES
1. CAPACITOR VALUES			
1.1 Each can :			
Capacitor 1	(nF)	220	AS SPECIFIED
Capacitor 2	(nF)	300	"
1.2 Alternative Effective Values			
Alternative 1 (all in series)	(nF)	63	"
Alternative 2 (2 x Cap 1 in series)	(nF)	110	"
Alternative 3 (2 x Cap 2 in series)	(nF)	150	"
1.3 Tolerances	(%)	±5	"
2. VOLTAGE RATINGS (50 Hz) (for each alternative)			
2.1 Continuous	(kV RMS)	50	"
2.2 1 Minute x once every 24 Hr	(kV RMS)	70	"
3. SHORT CIRCUIT CURRENT			
3.1 From 70 kV dc charge :			
- 5 discharges per 24 Hrs through a resistance across terminals	(ohm)	10	"
4. INSULATION LEVEL (line to ground)			
- 50 Hz continuous rating	(kV)	48	50
- 60 Second withstand	(kV)	95	140
- Lightning Impulse Withstand	(kV)	250	300

LS/DB/SPECLS

NWS 1412 : REVISION 0
DISTRIBUTION : STANDARD

E S K O M

S P E C I F I C A T I O N

FOR

S E R I E S C O M P E N S A T I O N R E A C T O R

CONTENTS

1. *SCOPE*

This specification is specific to a series compensation reactor to be used in an experimental pilot scheme.

2. *GENERAL*

Reference Documents

The reactor shall comply with the latest issues of the following documents. In cases of conflict, however, this specification shall take precedence.

2.1 *Eskom Standard Specification*

NWS 1532 : - Specification for large power transformer (in excess of 2 MVA)

2.2 *International Electrotechnical Commission*

IEC 289 : - Reactors

2.3 *British Standards Institution*

BS 5135 : - Metal-arc welding of carbon and carbon maganese steels

3. *CONSTRUCTIONAL DETAILS*

3.1 *Holding-down Bolts*

Each reactor shall be supplied complete with hot-dip galvanised holding-down bolts.

The holding down bolts shall be suitable for a 15 mm thickness of supporting structures top plate in the case of steel and suitable for grouting in the case of concrete.

3.2 Rating and Diagram Plates

In addition to the information specified in IEC 289 the rating plates shall show the Eskom Order Number and shall be provided with a blank space for the Eskom Asset Number.

3.3 Fittings

The following fittings shall be provided :

(a) Oil-immersed Reactors :

conservator tank
oil level indicator
dehydrating breather
gas actuated relay
dial type thermometer (top oil)
drain valve
rating and diagram plate
earthing terminal for 50 x 3 mm copper strap
lifting lugs
underbase for mounting on steel structure or concrete foundations

4. TYPE AND ROUTINE TESTS

4.1 Type and routine tests shall be performed as specified in IEC 289 and NWS 1532 where relevant.

4.2 A price shall be given fro performing a short-circuit withstand test (special test) in accordance with IEC 289 Clause 10.9.

If unable to perform this test as their works, manufacturers shall submit their proposal(s) to comply with the above test requirements.

5. DRAWINGS AND INSTRUCTION BOOKS

5.1 Contract Drawings

In addition to the drawings listed in Clause 14. of NWS 1532 where applicable, the following drawings shall be supplied:

5.2 Instruction Manuals

Instruction manuals shall be provided in accordance with Clause 14.2 of NWS 1532 where relevant.

SCHEDULE A : PARTICULARS OF ESKOM'S REQUIREMENTS
SERIES CURRENT-LIMITING REACTORS

	SCHEDULE A
1.1 Delivery and Off-loading	
(a) Delivered to	Apollo Sub-station
(i) Reactors	
(ii) Spares	
(b) Delivery effected not before	
(c) Off-loading from transport vehicle	By supplier
(d) Transferred to intended operating position	By supplier
1.2 Erection and Oil Filling	
(a) Erection ready for service	Yes
(b) Erection completed not later than	14/02/1992
(c) Supplied filled with oil (if applicable)	Yes
(d) Filled with oil which will be supplied by Eskom and made available on site	
1.3 Site Details	300 m
(a) Access to site	Gravel Road
(b) Crane for off-loading	No
(c) Distance from off-loading position	
(d) Nature of ground to be traversed	
(e) Rise or fall in metres	
(f) Construction supply available	No

		SCHEDULE A
1.4	*Quantity*	
(a)	No. of single-phase firm units required	1
(b)	No. of single-phase optional units required	1
(c)	No. of three-phase firm units required	0
(d)	No. of three-phase optional units required	0
1.5	*Type and Rating*	
(a)	Installation	Outdoor
(b)	Mounting	Steel structure
(c)	Type of cooling	ONAN
(d)	Continuous rated current in amps	2,3
(e)	(5 minute overload) rated current in amps	5
(f)	Maximum internal resistance at 75°C in ohms	283
(g)	Total inductance in H	45 ± 4%
(h)	Frequency in Hz	50
1.6	*Windings*	
(a)	Insulation	Fully insulated
(b)	Power frequency one minute voltage withstand test in kV RMS	140
(c)	Interturn overvoltage withstand test in kV (total voltage across winding)	140
(d)	Impulse withstand test voltage (1,2/50 microsecond full wave) in kV peak	350

	SCHEDULE A
1.7 Bushings or supporting pedestal insulator	
(a) Power-frequency one-minute wet-withstand test voltage at sea level, in kV RMS	70
(b) Impulse withstand test voltage at sea level (1,2/50 microsecond full wave) in kV peak	350
(c) Minimum total creepage distance in mm	1250
(d) Arcing gaps required	No
1.8 System details	
(a) Rated voltage of system connected to reactor input terminals in kV phase to ground	44
(b) Number of phases	1
2. BUSHING CT's	
(a) Number of cores	2 cores on primary bushing
(b) Turns ratio	1/2,5
(c) Class	x
(d) Min. secondary knee-point voltage (V)	60
(e) Max. secondary magnetising current (mA)	150
(f) Max. secondary resistance (ohm)	1
3. SPECIAL REQUIREMENTS (refer to clauses in NWS 1532)	
3.1 Corrosion Protection and Paint Finish	As per Standard Transformer Specification

SCHEDULE B : GUARANTEES AND TECHNICAL PARTICULARS OF EQUIPMEN OFFERED

	SCHEDULE B
1. PERFORMANCE DATA	
1.1 Continuous current rating	amps 2,3
1.2 (5 minute overload) current rating	amps 5,0
1.3 Inductance per phase within tolerances :	45
(a) at rated current	
maximum henries	46,8
minimum henries	43,6
(b) at 5 minute overload current	
maximum henries	
minimum henries	
1.4 Total real power loss at continuous rated current, at 75°C in watts	1323
1.5 Temperature rise at site altitude in °C, at continuous rated current :	
(a) top oil (if applicable)	°C 50
(b) windings (by resistance)	°C 55
(c) hottest spot	°C 60
1.6 Temperature rise at site altitude in °C after carrying current for 5 minute overload	
(a) Final calculated winding temperature	80°C
(b) Initial temperature on which this is based	40°C
1.7 For magnetic core reactors :	
(a) Maximum flux density in magnetic circuit at continuous rated current and frequency in tesla.	1,6
(b) Current at which saturation occurs.	2,7 Amp RMS

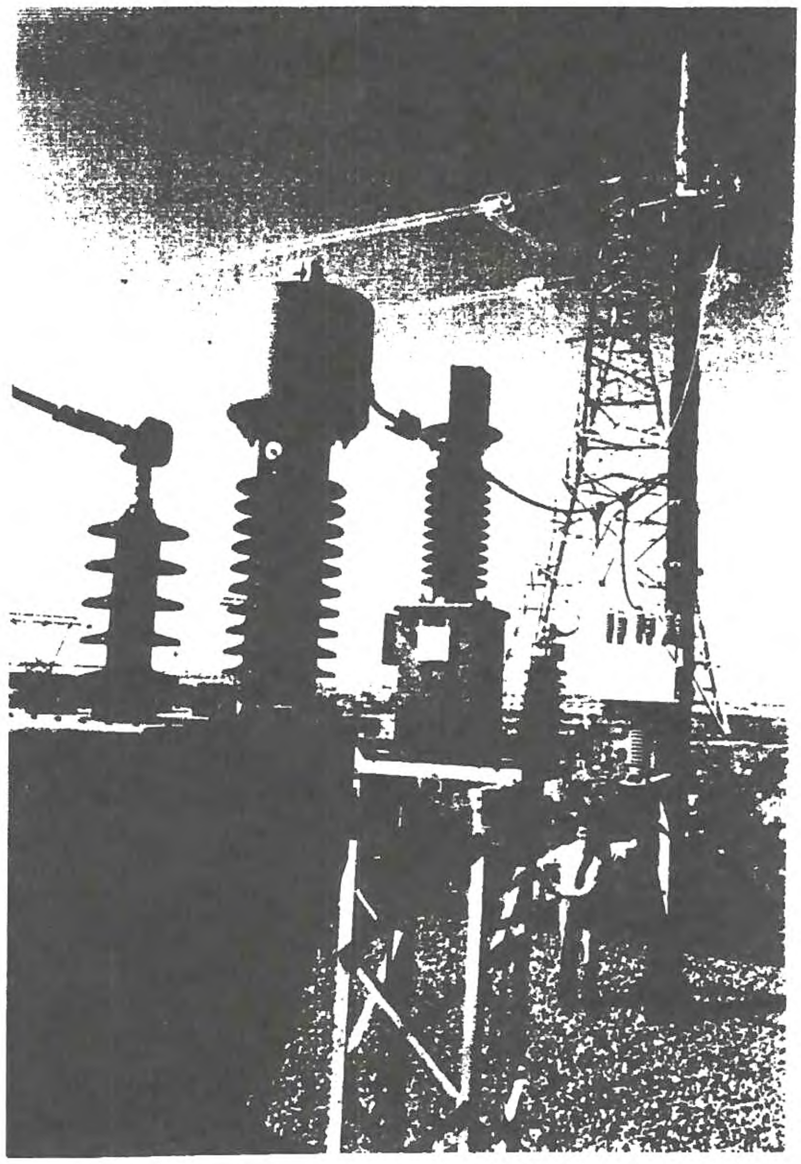
	SCHEDULE B
2. *INSULATION*	
2.1 Windings	
(a) Power-frequency one minute withstand test voltage to earth, in kV RMS	140
(b) Inter-turn overvoltage withstand test	
(i) voltage	kV RMS 140
(ii) frequency	Hz 50
(iii) duration	sec 60
(c) Impulse withstand test voltage (full wave)	
(i) voltage	kV peak 300
(ii) wave shape	microsecond 1,2/50
2.2 Bushings	
(a) Type	OP36 / EP250
(b) Power-frequency, one minute wet-withstand test voltage at sea level in kV RMS	95 / 140
(c) Impulse withstand test voltage at sea level (full wave)	kV peak 200/250
(d) Total creepage distance in mm	865 / 1100
(e) Protected creepage distance in mm (90° rain)	237 / (765)
2.3 Supporting pedestal insulator	
(a) Type	
(b) Power-frequency, one minute wet-withstand test voltage at sea level in kV RMS	
(c) Impulse withstand test voltage at sea level (full wave)	kV peak
(d) Total creepage distance	mm
(e) Protected creepage distance (90° rain)	mm

	SCHEDULE B
3. *GENERAL INFORMATION (where applicable)*	
3.1 *Manufactures of :*	
(a) Reactor	
(b) Bushings	
(c) Pedestal insulators	
3.2 *Type of reactor*	
(a) Air core or magnetic circuit	Magnetic
(b) Oil immersed or dry type	Oil
3.3 *Type of cooling*	ONAN
3.4 Current density in winding at rated current, in amperes per mm^2	2,3
3.5 *Oil quantities, in litres :*	
(a) Reactor tank	300
(b) Coolers and conservator	100
(c) Total	400
3.6 *Weight in kg :*	
(a) Core and windings	247
(b) Tank shielding and fittings	177
(c) Coolers	
(d) Oil	360
(e) Total including oil	934
(f) Heaviest transportation weight	960

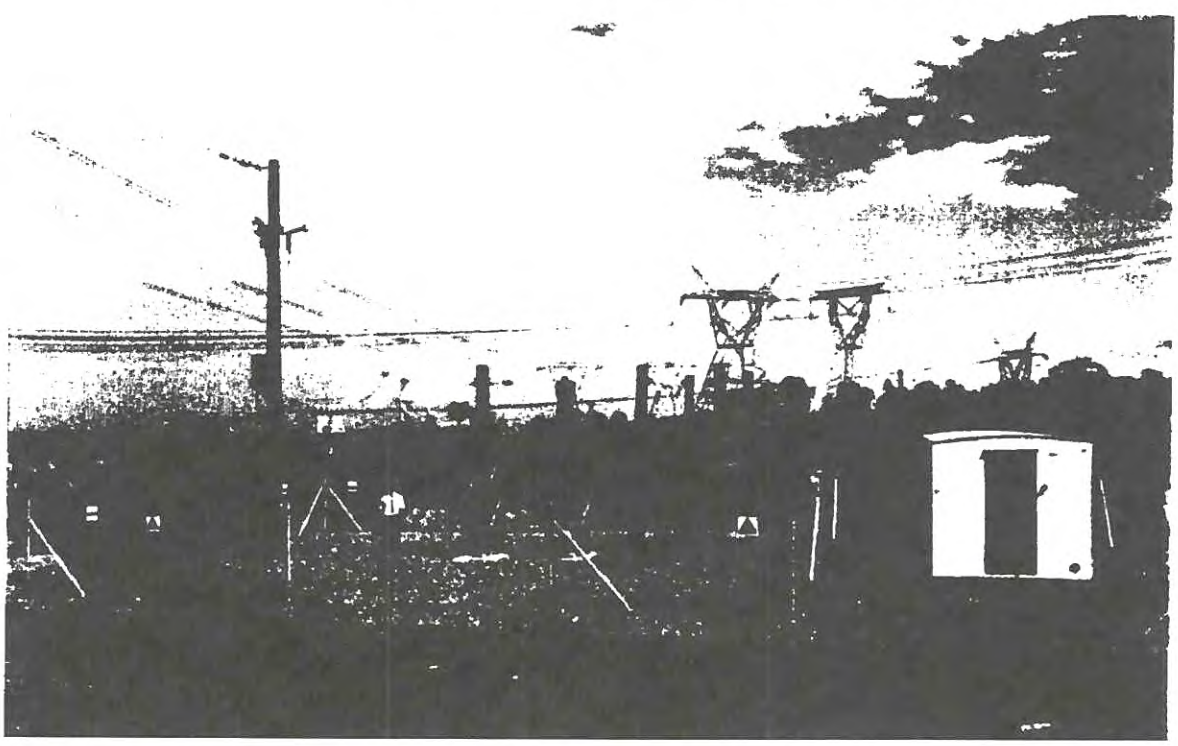
	SCHEDULE B
3.7 Filling medium for transport	
3.8 Overall dimensions	
(a) Complete unit :	
height	mm 2350
length	mm 1370
breadth	mm 750
(b) Tank only :	
height	mm 730
length	mm 850
breadth	mm 750
(c) Height over HV bushings	mm 1070
3.9 Tank and cooler material thickness in mm	
(a) Sides	5
(b) Bottom	5
(c) Top	5
(d) Conservator	3
(e) Cooler plate	-
(f) Cooler tubes	-
4. CONTRACT DRAWINGS	
Is supply of contract drawings guaranteed in terms of Clause 14.1 of NWS 1532.	~~Yes~~/No
5. SPECIAL REQUIREMENTS	
5.1 Primary bushing CT	
(a) Turns ratio	1/2.3
(b) Class	X
(c) Min. secondary knee-point voltage (V)	60
(d) Max. secondary magnetising current (mA)	120
(e) Max. secondary resistance	1.0

APPENDIX G PHOTOGRAPHS OF PROTO-TYPE SYSTEM

RIGHT: Author standing with the experimental shielwire supply system.
COMPONENTS : (Foreground to background) Reactor, Current Transformer, Surge Arrester, Capacitor, Pole Mounted Switch Gear and Transmission Line.



BELOW:
View of shieldwire supply system including the distribution transformers, port-a-camp building and fence.



APPENDIX H DESCRIPTION OF MOBILE MEASURING FACILITY

MOBILE TRANSIENT MEASURING FACILITY

By : C Cothill 11 February 1993

1. INTRODUCTION

The mobile transient measuring facility, of Technology Research and Investigations is designed to provide a full scale on-site study of transmission system phenomena in the field of transient and high frequency disturbances. Based on the specifications detailed below, the laboratory has the following capabilities:

1.1 Multichannel High Speed Data Acquisition - up to 5MHz bandwidth.

1.2 Data storage and hardcopy plotting.

1.3 On-site waveform analysis.

1.4 Stand alone continuous monitoring.

2. MEASURING INSTRUMENT

2.1 Nicolet System 500

Miltipro Digitizer	: Type 140
Number of channels	: Up to 12
Memory size	: 1 M samples/channel
Resolution	: 12 bits
Digitizing rate	: 10MS/sec

Multipro Digitizer	: Type 160
Number of channels	: Up to 6
Memory size	: 1 M samples/channel
Resolution	: 8 bits
Digitizing rate	: 200MS/sec

2.2 Multipro 200 Advanced Trigger Board

The Multipro 200 advanced trigger board provides the following additional trigger detections:-

2.2.1	Bus Triggers	: Minimum Intervals, Drop-out, hold-off, single event and slave.
2.2.2	External Triggers	: Gate, Glitch, Pulse, Min Interval and Drop-out.

2.3 Computer Control

The Nicolet 502 is computer controlled and the following main features are available on the system:-

* Automatic data acquisition.
* Fourier analysis.
* Arithmetic Calculations on recorded waveforms.
* Stand alone monitoring.

3. INTERFACING EQUIPMENT

3.1 Tektronix Voltage Probes

Attenuation Ratio	: 1000 : 1 (Variable by about 9%)
Max. Input Ratio	: 13kV (DC or RMS)
	: 18kV peak (Pulse)
Bandwidth (-3dB)	: DC to 75MHz
Risetime	: 4,67µSec

3.2 Pearson Current Transformer

Three Units available

Max. Peak Current	: 50kA
Nominal Current Rating	: 400A rms at 50Hz
Bandwidth (-3dB)	: 5Hz - 2MHz
Risetime	: 200µSec
Transducer	: 10mV = 1 Amp
Internal diameter	: 85mm

3.3 Fibre Optic Link

Number of channels	:	10
Fibre Optic Cable Length	:	100m (x 10)
Bandwidth	:	DC - 7MHz
Risetime	:	50µSec
Voltage	:	4Vp-p

The interfacing brakes and CT's can be coupled via Fibre Optic systems to provide High Voltage isolation.

3.4 Nicolet Isobe 3000 (Fibre Optic Isolated Probes)

Number of channels	:	4 (+6 on order)
Fibre Optic Cable Length	:	100m (x 3)
	:	50m (x 1)
Bandwidth	:	15MHz (-3 dB)
Risetime	:	25µSec
Voltage	:	2 Vp-p

The interfacing probes and CT's can be coupled via Fibre Optic systems to provide High Voltage Isolation.

3.5 Haefely High Voltage RC Divider

(6 Stacked elements each providing 1000 : 1 stepdown ratio).

Rated Voltage

3.5.1 400kV system (up to 3 phases)
RMS per phase : 300kV at 50Hz
Lightning impulse (1,2/50µS) : 1450kV 20kHz
Switching impulse (250/2500µS) : 1140kV

3.5.2 765kV system (2 phases)
RMS per phase : 445kV at 50Hz
Lightning impulse : 2100kV

Switching impulse : 1470kV

Bandwidth/Risetime : DC to 5MHz/70µSec risetime

The mobile unit has an on board crane with accessories for the erection of the haefely dividers.

3.6 Eskom Resistive Dividers (3 Units)

Maximum Voltage	: 50kV at 50Hz (line to ground)
Ratio	: 270 : 1
Bandwidth	: DC -1MHz

4. GENERAL INFORMATION

4.1 The mobile laboratory can be supplied by either 3 phase 380V station supply or an on-board diesel generator. All recording instruments are supplied via an Uninterruptable Power Supply providing 20-40 minutes back-up power.

4.2 The facility is fully self-contained and electrically shielded. All instruments and associated equipment travel as a single unit.

5. STAND ALONE MONITORING

The digital instruments are all computer controlled and can be programmed to trigger on an event, store and re-arm. Future developments include the possible addition of a computer modem for the Nicolet system. This would facilitate the continuous processing of data, when the facility is monitoring at a remote site, while avoiding the cost of transporting personnel to site on a regular basis.

6. MEASURING TEAM

The unique combination of sophisticated equipment and personnel experienced in, and dedicated to the field of transient measurements cannot be overstressed. Significant results can be obtained from measurements, conducted by the facility, which are likely to be used for strategic technical decisions in the field of transmission or substation design and optimisation. Accuracy and reliability are therefore paramount.

The PNT facility has been developed, and enhanced, by a team of competent technologists who have had extensive exposure to the difficulties of conducting field evaluations. As a result the laboratory has been designed to overcome many of the pit-falls endemic in indoor and outdoor high voltage environments.

Measuring reliability and efficiency is further enhanced by the development of appropriate techniques in the application of all instrumentation and equipment. The team has a sound knowledge of the phenomena typically being measured and evaluated. Furthermore each team member has, through experience, developed a thorough insight into the application, operation and limitations of the various instruments and associated interfacing equipment. Familiarity with the layout of high voltage sub-stations and on-site operating procedures is yet another important feature of the team's ability.

7. CONCLUSIONS

PNT has, at its disposal, a unique mobile measuring capability, which can be applied to evaluate a large variety of overvoltage phenomena. The facility consists of state of art measuring equipment as well as experienced personnel specialising in high resolution, multi-channel, transient measurements. Practical data can be obtained from various points throughout Eskom's transmission system during either switching events, fault conditions or lightning. Such information can be used to develop and verify computer based design models and diagnose system irregularities. Utilisation of the facility during the commissioning of sub-stations should also be considered.

8. FURTHER INFORMATION

Please contact C Cothill (011) 629-7079 or JD Masters (011) 629-7080.

APPENDIX I QUOTE FOR SCC1 FROM BG CHECO

☎ 2634790930 P. & F. ZIMBABWE 08/10 '91 12:53 P01

230F/91/I

Serial Number.	P.O. Box GD 38 Greendale Harare	Facsimile: 790930
PROJECTS AND FINANCE ZIMBABWE (Private) LTD '91 OCT -8 12:13		13238.

TO: ESKOM	Country. RSA	Attention. L. STUBBS

Our Reference. PA/GENERAL/CANADA	Telefax Number. 119-27-11-800-4299.

Date. 7.10.91	Sender. P. ALLSOP	Your Reference.	No. of Pages Incl. this Page. 1

RE: OVERHEAD GROUND WIRE POWER TAP SCC 1

Further to your enquiry dated 26 September 1991 please find detailed below the contents of a reply received from HV Networks/B.G. Checo, Canada.

QUOTE

I will just give you here a quick answer to your quesions:

1. Estimated max, power from 10 km of insulated ground wire between 40-70 kVA, exact figure to follow.

2. Since all the equipment of SCC-1 except the control cabinet are standard equipment, we would sugesst that ESKOM source the equipment according to our specifications. We would provide you with Specifications, Instruction Manuals, drawings, Control Cabinet, spare electronic board as well as commissioning and training on the first unit, estimated rough price in U.S. dollar F.O.B. Montreal:

1st unit	(in the same order)	100 000.00
2nd & 3rd units	(in the same order)	95 000.00
4th & 10th units	(in the same order)	90 000.00
Over 10 units		85 000.00

Rough estimate of the balance of the equipment could be between U.S.$ 60 000.00 to 100 000.00.
More exact figures to follow.

UNQUOTE

Further information will be forwarded to you following its receipt from HV Networks.

Regards

PHIL ALLSOP
PP CONTRACTS MANAGER

REFERENCES

Berthiaume, R. and Blais, R. (1977)
Tapping the overhead wire on transmission lines produces a 20 kW, 60 Hz power supply. **Report IREQ-1626.**

Berthiaume, R. and Blais, R. (1980)
Microwave repeater power supply tapped from the overhead ground wire on 735 kV transmission lines. **IEEE Transactions on power Apparatus and Systems**, vol. PAS-99, No.1, pp.183-184.

Gururaj, B.I. and Nandagopal, M.R. (1970)
Design parameters for earth wire power tapping. **PROC. IEE**, vol.117, no.1, pp.177-182.

Ruest, D. and Sybille, G. (1990)
Capacitive coupling systems (SCC) to provide reliable HV tapping. **Private correspondence with Authors:** BGCheco International Ltd, 7151 Jean-Talon East, suite 1000 Anjou, Quebec, Canada H1M 3R4.

Sarma Maruvada, P. and Harbec, G. (1978)
Capacitive power tap-off from transmission lines using ground wires: Calculation of the equivalent circuit parameters. **IEEE Transactions on power Apparatus and Systems**, vol. PAS-97, No.4, pp.1194-1201.

Sturton, A.B. (1971)
Supply of small distribution load from transmission. **For Presentation to the Canadian Electrical Association, Electrical Apparatus Section.**

Annexure - IV

Capex investment/Location (BOQ Based on demo set-up and rates are as per KPMG Recomendation)

Sr. No.	*Description of Item*	*Unit*	*Qty. for single location*	*Unit Rate (Rs)*	*Total (Including GST) (Rs)*
1.0 : Asset of life 15 Year					
1.0 (A) -Supply (GST Rates @ 18%)					
1	Power Potential Transformer (1-Phase) as per Specification	No.	1	400000	400000
2	Gapless Surge Arrestor (1-Phase) as per specification	No.	1	45000	45000
3	Clamp/Connectors for above PT and SA	Set	1	15000	15000
4	70 KN Tension Hardware Fitting alongwith arching horn	No.	15	3088	46320
5	25KN Suspension Hardware Fitting alongwith arching horn	No.	7	3156	22092
6	66 Kv Phase to Earth or 132kV Phase to Phase Polymer Insulator 70KN Rating with Socket & Ball (Polymer Length = 1305mm, Creepage distance = 4495mm).	No.	22	3431	75482
7	66kV Polymer Support Insulator (Polymer Length = 1305mm, Creepage distance = 4495mm) with clamp suitable for 7/3.66mm Earth wire and bolted type base	No.	21	6861	144081
8	7/3.66mm Earthwire	Mtrs	60	69	4140
9	Platform for Power Equipment	MT	0.5	99900	49950
10	Platform for Telecom Equipment	MT	3	99900	299700
			Subtotal A=		**1101765**
1.0(B)- Installation (GST Rates @ 18%)					
1	Polymer support Insulator Installation	No.	21	1150	24150
2	Installation of Power Equipment PT & LA	LS	1	23000	23000
3	Modification in Tower for Installation of Telecom Antennas	LS	1	11500	11500
4	De-stringing of about 5-6 Kms earthwire, installation of Suspension and Tension Insulator String/Arching horn and restrining of earthwire, Clamp of Earthwire and its connection with PT & LA through polymer support insulator. PT output connectction to Telecom equipment, Power equipment earthing connection with Tower earthing and Testing and commissioning thereof.	LS	1	345000	345000

Sr. No.	*Description of Item*	*Unit*	*Qty. for single location*	*Unit Rate (Rs)*	*Total (Including GST) (Rs)*
			Subtotal B =		**403650**
1.0 (C) -F&I (GST Rates @ 18%)					
1	Power Potential Transformer (1-Phase) as per Specification	No.	1	23000	23000
			Subtotal C =		**23000**
	Total 1.0 (A+B+C) (Including GST)=				**1528415**
2.0 : Asset of life 7.5 Year					
	Battery Charger with remote monitoring system	No.	1	190000	**190000**
3.0 : Asset of life 7.5 Year					
	Battery Bank	Set	1	245000	**245000**
	Total Capex Investment 1.0+ 2.0+ 3.0 (Including GST) =				**1963415**

Note : Installatio and Transportation cost of some BOQ items are included in supply rates.

Annexure - V

Operational expenses/Location/Month

Item Description	Bases of O&M Charges	Total Charges
Manpower Cost	(4 % of revenue of Rs.45,000/Month)	1800
Miscellaneous Admin expenses	(0.5 % of revenue of Rs.45000/Month)	225
Average Marketing Spend	(0.5% % of Revenue of Rs.45000/Tower/Month)	225
Miscellaneous operating expenses	(3 % of revenue of Rs.45000/Tower/Month)	1350
Watch and ward/ Insurance	@ 2500 per location per months	2500
Maintenance Cost - BB & SMPS	(5% of supply cost of Rs.435000)	1813
Maintenance Cost - Power PT & LA (% of Supply Cost)	(3% of supply cost of Rs.445000)	1113
Network Operating Centre Cost/ Tower	Rs.300/Tower/Month	300
	Operational expenses/Location/Month =	**9325**
	Annual operational expenses/Location	**111900**