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Central Electricity Generating Board

Planning Department

PLANNING MEMORANDUM PLM–ST–6

GENERATOR PERFORMANCE CHARTS

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PLANNING MEMORANDUM PLM–ST–6

GENERATOR PERFORMANCE CHARTS

SUMMARY

It is desirable that there should be, within the CEGB, a common method for the construction and presentation of generator performance charts. This Planning Memorandum describes such a method.

Recognizing present and immediate future system requirements, the accent is placed on the accurate definition of generator performance at leading power factors and less effort is devoted to the lagging power factor region.

Two types of generator arrangement are identified for the purpose of calculating operating limits, the classification depending upon whether the terminal voltage can remain constant or must vary as part of normal operation; directly connected generators are treated as a special case. Each possible performance limit is defined and the assumptions introduced to simplify chart construction are explained.

The step-by-step procedure for plotting a performance chart is given in Appendix B. Other appendixes list the symbols used, demonstrate the construction of performance charts for machines at Drakelow 'B' and Blyth 'A' Power Stations, and show the derivation of the equations used. Appendix G compares the manually prepared charts for the Drakelow and Blyth examples with those produced from the same data using a South Eastern Region computer program (CHRT) and a graphical plotter.

HOW TO USE THIS DOCUMENT TO PLOT A PERFORMANCE CHART

(1) **Identify Generator Arrangement (Clause 2)**

Is it on-load tap, off-load tap or directly connected?

(2) **Select Recommended Presentation (see 5.1 to 5.3)**

Decide values of system and terminal voltage and tap position to be used, location of metering points for which HV and LV charts will be drawn and whether additional charts will be used for other conditions.

(3) **Assemble Data (Appendix A, clause A1)**

(4) **Use Appropriate Construction Method (Appendix B)**

On-load taps – Clauses B1–B3
Off-load taps – Clauses B4–B6
Direct Connection – Clause B1, as directed in introductory paragraphs to Appendix B.

GENERATOR PERFORMANCE CHARTS

FOREWORD

The parameters of any generator and its associated plant may be used to plot a performance chart which will display the MW and MVAr operating limits for that generator.

In the past, performance charts have been either supplied by the generator manufacturer or plotted by CEGB Regional Technical Department staffs. The result has been that several methods have evolved for plotting performance charts and for selecting the practical generator stability limit and, in some cases, charts have shown generator MW and MVAr capabilities that cannot be obtained in practice.

It is desirable that there should be a common method for the construction of generator performance charts throughout the CEGB, and this Planning Memorandum describes such a method.

1. SCOPE

This Memorandum determines a method of plotting and presenting performance charts for various generator arrangements. It is valid for round-rotor machines only and should not be used for salient pole generators.

The operation of a generator at leading power factors must be restricted, both to ensure that it will remain stable in the event of a system disturbance and to prevent overheating. At lagging power factors, operation need only be restricted to prevent overheating. The method recommended for plotting charts recognizes the difference between these operational extremes and lays emphasis on factors which give the most accurate definition of the leading power factor limit, taking account of physical restrictions (e.g. transformer tap range) which may make it impossible for a generator to operate at its practical stability limit. In contrast, the lagging power factor limit has been treated simply: the effects of iron saturation, stator heating and rotor heating have been ignored and reliance has been placed on the relatively long times available during which excessive temperatures can be corrected.

2. GENERATOR ARRANGEMENTS

Generators are connected to the system either directly, through a reactor, or through a transformer. Generator excitation may be controlled manually or by AVR; transformer tap changing may be by on-load or off-load tap changer. A unit transformer may be connected to the generator terminals to provide auxiliary supplies.

Despite the multiplicity of possible generator arrangements, the method used for plotting performance charts depends only on whether the generator terminal voltage stays constant or varies throughout its operating range.

TABLE 1
Type of Generator Arrangement

Type	Generator Terminal Voltage	Method of Connection
1	Remains Constant	(i) On-load tap transformer (ii) Direct
2	Varies	(i) Off-load tap transformer (ii) Reactor*

*If the generator terminal conditions are not metered, the chart should be plotted as for a directly connected generator, Type 1(ii) (i.e. the reactor is treated as part of the generator).

For transformer-connected generators, variation of the load or the excitation will cause a change in generator terminal voltage which can be corrected by altering the transformer tapping. Thus, if the generator transformer has an on-load tap changer, it will be possible to operate at constant terminal voltage anywhere within a range of MW and MVAr loading for various values of HV voltage but, if the taps can only be changed off load, a similar operating range will only be achieved by allowing the terminal voltage to vary.

The Type 1 construction used for directly connected generators assumes that the terminal/system voltage can be regarded as constant. While this may not be strictly true, it is recommended that high, normal and low system voltage limits should be shown on the chart (clause 4.1) so that it is possible to interpolate for intermediate voltages if the voltage varies.

The generator-reactor arrangement is usually treated as a directly connected generator of higher reactance and the conditions at the terminals of the generator itself are not metered. However, if a chart is required for terminal metering for such an arrangement, it would have to be treated as Type 2 with a 1 : 1 transformer ratio.

Synchronous compensators and declutched gas turbines operating as synchronous compensators are not included in the above table; the performance chart would be a horizontal line along the MVAr axis.

3. LIMITS OF GENERATOR PERFORMANCE

Fig. 1 shows the limitations on generator performance which, together, form the performance chart. While it is unlikely that all of these limits would apply to any one machine, they are shown here for completeness (e.g. if a tap limit (PQ) applied, the practical stability limit (BC) would become irrelevant). The limits are discussed in the subsequent paragraphs.

3.1 Minimum Excitation

The portions AB and A^1B^1 are the minimum continuous excitation loci. These will depend upon the minimum generator rotor currents that can be achieved, with the main field switch closed, under AVR and manual excitation control, respectively. These curves will normally be coincident but may differ on some generators. Care should be taken to ensure that this minimum value is not limited by incorrect setting of the main exciter negative field, where fitted, and that the brushes are of suitable grade for these low values of rotor current.

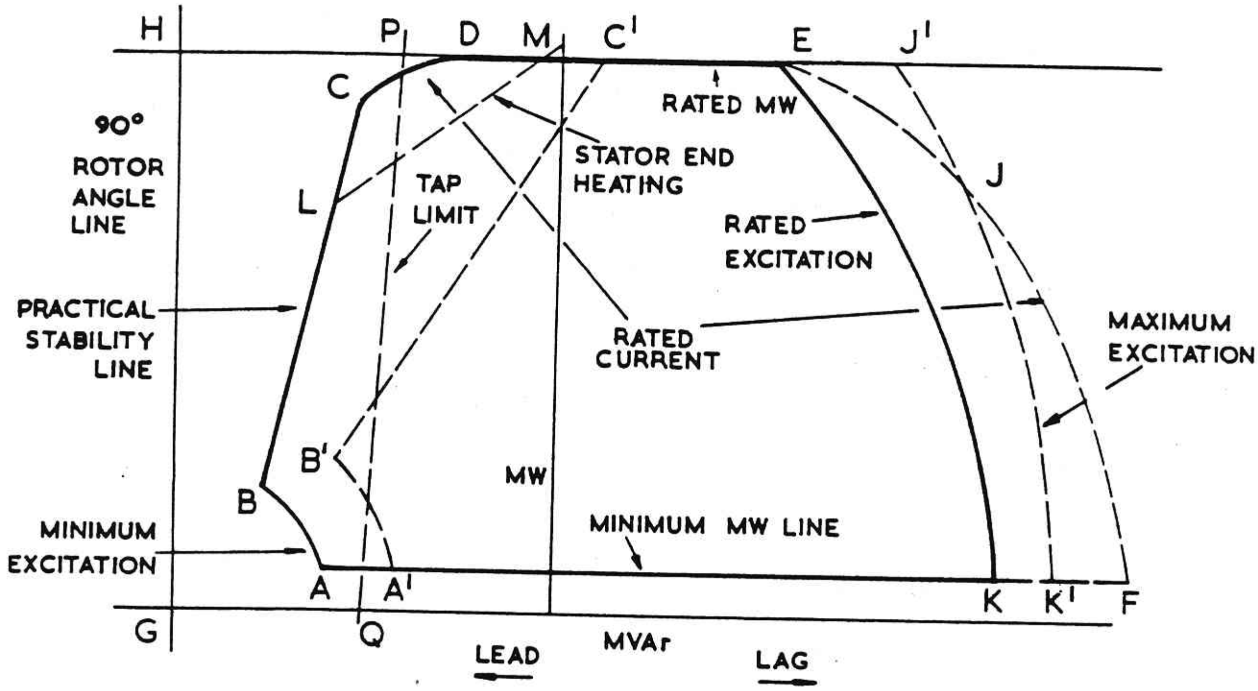


FIG. 1

3.2 Rated Current

Lines CD and EF are portions of the locus of the rated current for the generator stator or transformer, whichever is the smaller, bearing in mind that for a Type 2 arrangement the terminal voltage of the generators may be depressed, particularly when operating at leading power factors.

3.3 Rated MW Output

The portion DE is the rated MW output limit of the main generator. This is not necessarily the name plate rating of the generator as it may have been re-rated.

3.4 90° Rotor Angle

The line GH represents the 90° load angle of the generator to its own terminal voltage vector and is used in the construction of the practical stability limit line. This line does not represent the theoretical stability limit line of the generator at constant excitation or under AVR control because the generator terminals are not connected to infinite busbars but to a finite power system with varying generating demand and system conditions.

The line will not be vertical for generator arrangements where the terminal voltage varies (Type 2).

3.5 Practical Stability Limit

Lines BC and B^1C^1 are the arbitrary stability limits for a machine under AVR and manual control respectively. The stability margins used depend on the category of the excitation control system as defined in Generation Design Circular No. 14 as follows:

Category 1

Continuously acting automatic regulators (having no dead-band) with VAr limiters.
MW margins: 4 per cent at full load; 10 per cent at no load.

Category 2

Automatic regulators having some dead-band and with VAr limiters.
MW margins: 10 per cent at full load; 10 per cent at no load.

Category 3

(i) Any type of regulator which is not fitted with a VAr limiter or has limiter not in operation.
(ii) Any excitation control system which is not automatic (e.g. the 'hand' control position on an excitation system).

MW margins: 20 per cent at full load; 20 per cent or 10 per cent at no load.

(Generation Design Circular No. 14 gives requirements to be satisfied for 10 per cent.)

Whatever the category of AVR, the arbitrary practical stability limit line should be checked to ensure that it can be achieved in practice. The AVR control ranges provided may make it impossible to follow the arbitrary line: this applies particularly to machines that have off-load taps on the generator transformer. Similarly, it may not be possible to make the excitation limiter match the arbitrary limit line throughout its range.

If for these or similar reasons the arbitrary line does not coincide with what can be achieved in practice, then the actual practical stability limit line should be shown on the chart.

Tests have indicated that the use of high-speed continuously acting AVRs can allow stable steady-state operation at rotor angles in the region of 130°–140°. However, transient stability considerations, taking account of network impedance and the disposition and performance of other generators on the system, make operation at these high angles unacceptable. Therefore, the limits listed above must be observed. (These give rotor angles of about 75°, 70° and 60° for Category 1, 2 and 3 machines, respectively.)

3.6 Maximum Excitation Limit

The most useful representation of this limit is the curve EK, which is an arc of a circle with centre G. This is, in fact, the locus of the excitation current for rated load and power factor, ignoring the effect of saturation; the true maximum excitation current may be slightly higher (J^1K^1). The exclusion of saturation, and the avoidance of the associated calculations, simplifies the construction of the chart but results in an overstatement of the lagging MVAr capability by an amount varying from zero at full-load to about 10 per cent of the MVA rating at no-load. This is considered acceptable since generators are only likely to require maximum excitation when operated at or near full-load. Since a generator is designed to operate at a particular rating or over a certain range without exceeding British Standard temperature rises, no part of the generator or associated circuits should be allowed to operate above the specified levels during the guarantee period. Therefore, if the manufacturer's twelve-month guarantee has not expired, the excitation current must not exceed that for rated load and power factor.

It may be acceptable when the guarantee has expired to operate at higher excitation currents provided that Regions are satisfied that this will not result in overheating (Generation Division would be prepared to advise Regions if required). The lagging limit is then defined by EJK^1.

3.7 Minimum MW Output Limit

The portion AF is a minimum MW line below which sustained operation of the generator is not possible. Some of the factors which prevent operation at lower loads are as follows:

(i) Low turbine vacuum, resulting in high temperatures of turbine LP stages.
(ii) Expansion and clearances of prime mover parts.
(iii) Rate-of-reloading.
(iv) Boiler minimum steaming conditions; varies with range or unit construction.
(v) De-aerator problems associated with permissible oxygen content of feed water.

In those cases where it is difficult to establish the minimum line precisely, the best estimate should appear on the chart, but other constraints at lower loading should be shown as well (e.g. minimum excitation limit).

3.8 Stator End Heating

The portion LM is a restriction which may occur on some generators at leading, and possibly lagging, power factors due to local stator-end heating.

The limit can be established only on those generators fitted with stator-end iron thermocouples, and the determination of the locus would require a special test on the specific generator.

3.9 Tap Limit

A condition may arise where a generator operating at constant terminal voltage, with an on-load-tap transformer, cannot achieve full MVAr absorption at a given HV system voltage because the transformer has reached its extreme negative tap (minimum turns ratio). This restriction is represented by line PQ.

Operation at a more leading power factor could only be achieved by reducing the terminal voltage; this in turn would cause the practical stability limit line BC to move to the right until an optimum operating point was reached.

3.10 Generator Transformer Overfluxing Limit

Operation at maximum generator MVAr absorption and constant terminal voltage entails tap changing to reduce the turns ratio of the transformer (i.e. removal of turns from the HV winding). Dependent on the HV voltage and the nominal working flux density of the transformer, a tap position may be reached at which the transformer iron becomes progressively more saturated, causing high iron losses, high iron/oil temperature gradients or excessive core bolt temperatures. Modern generator transformer cores are designed with a nominal density of 1.8 tesla, using cold rolled steel, and a limit of 1.9 tesla is regarded by the CEGB as the maximum permissible density.

CEGB Design Memorandum 099/61 describes the fundamental aspects of transformer overfluxing, the operational circumstances in which it may occur and the measures taken to minimize its adverse effects. Appendix A to that Design Memorandum deals specifically with overfluxing in generator transformers and defines an equation for the limiting value of reactive power to prevent overfluxing. That equation is used in the Appendixes to this Planning Memorandum to determine the overfluxing limit on the generator performance chart.

While the location of the overfluxing limit should be checked for all generator transformers, the older transformers which have cores of hot-rolled steel and which operate at lower flux densities are unlikely to impose a limit.

If overfluxing restricts generator MVAr absorption capability, reduction of the generator terminal voltage will cause the overfluxing limit line and practical stability limit line to move left and right, respectively, until maximum possible MVAr absorption is achieved.

4. CONSTRUCTION OF PERFORMANCE CHARTS

The following clauses define a number of assumptions which simplify the construction of a generator performance chart, without significantly reducing its accuracy, and then refer to the procedure used to determine the various limits which together produce the outline of the chart.

4.1 Assumptions

4.1.1 Losses

It is assumed that the mechanical shaft input power equals the electrical power delivered to the network.

4.1.2 Saliency

In view of the small degree of saliency of most machines on the system (rarely more than 5 per cent), saliency has been ignored and the generator has been assumed to have a round rotor. (It has been estimated that the inclusion of 5 per cent saliency when plotting a chart would show an improvement in MVAr absorption of about 2½ per cent at 5 per cent load falling to much less than 1 per cent at 50 per cent load.)

If it is necessary to plot a performance chart for a hydro machine with high saliency, guidance on the effect of saliency is given in IEE Paper 4699P.

4.1.3 System Frequency

Assumed to be constant 50 Hz.

4.1.4 Generator Saturation

No allowance has been made for variation of the synchronous reactance (x_d) with loading or terminal voltage. This assumption makes little difference at leading power factors but may cause appreciable over-estimates at lagging power factors. (See also 3.6.)

4.1.5 HV System Voltage

It is assumed that the HV system voltage (or the switching voltage in the case of a directly connected machine) remains constant irrespective of generator loading. This is acceptable because the chart should show limits for more than one system voltage (see clause 4) and limits at intermediate system voltages can be determined by interpolation.

4.1.6 Short-circuit Level and Transient Stability

Report PL–ST/28/72 describes an approximate method for the rapid assessment of transient stability limits on large generators. The report demonstrates that, at time of light load when system post-fault short-circuit levels are low, operation at the practical stability limit could result in generator instability in the event of a fault close to the busbar at which the generator is switched. It is not intended that transient stability limit lines should be added to all performance charts, although they may be useful on charts for generators likely to be running at light load times on weakened systems.

4.1.7 Unit Transformer Loading

This is assumed to be constant at all levels of generator output.

4.1.8 Voltage Indication

In order to use the performance chart it is necessary to know the generator terminal voltage and the HV system voltage. It is assumed that indication of either or both of these voltages is available to the user.

4.2 Steps in Construction

A detailed step-by-step description of the determination of each performance limit and the subsequent construction of a generator performance chart is given in Appendix B. Six separate sets of instructions cover the possible need to plot a chart for either a Type 1 or Type 2 generator arrangement (i.e. terminal voltage remains constant or varies) relating to either the HV or LV side of the generator transformers or the generator terminals.

As described in the introductory paragraphs to Appendix B, the chart for a directly connected generator should be constructed using the equations for the Type 1 generator arrangement, i.e. a generator connected through a transformer with on-load tap change facilities. Reactor-connected generators can be treated in the same way if the reactor is regarded as part of the generator reactance but, if there is metering at the generator terminals, the chart must be constructed as for a Type 2 generator.

The symbols used, the data needed and the sign convention adopted are described in Appendix A and the derivation of the equations used in Appendix B is given in Appendixes E and F. Appendixes C and D show worked examples of the construction of performance charts for actual Type 1 and Type 2 generator arrangements at Drakelow 'B' and Blyth 'A'.

South Eastern Region have developed a computer program (CHRT) for use in conjunction with this Memorandum. The program calculates the performance limits for a generator using the same data and generally the same theory as this Memorandum. The output of the program can be fed into a graphical plotter to obtain a performance chart. Appendix G describes the differences between CHRT and the methods detailed in this Memorandum and includes computer drawn charts for the Drakelow 'B' and Blyth 'A' machines used as worked examples. The charts are compared with those constructed manually in Appendixes C and D.

5. PRESENTATION OF PERFORMANCE CHARTS

It would be possible to prepare a chart showing the limits of generator performance for all possible values of system voltage, transformer tap position and, for Type 1 arrangements, generator terminal voltage. However, such a chart would have so many lines that it would be difficult for the user to interpret it. The presentation can be simplified by excluding variations of parameters that are normally kept constant, e.g. terminal voltage in Type 1 arrangements and tap position in Type 2 arrangements. While it is unlikely that the terminal voltage will be varied regularly during normal operation, it is possible that a different terminal voltage may be adopted, for a period, to satisfy a particular system condition. In this event, another performance chart should be plotted for the new terminal voltage. The same applies to an off-load tap position other than that in normal use.

In Type 1 arrangements it is only necessary to take account of the tap limit for extreme negative tap (minimum turns ratio) since this is the tap position which permits operation at the most leading power factor. Adjustment of the loading, excitation or on-load tap will enable the operator to move the operating point of the generator anywhere within the limits of the chart and there is no need to define the limit of operation for each tap position.

The tap limit line plotted for the opposite end of the tap range (i.e. extreme positive tap – maximum turns ratio) is unlikely to prove a restriction on lagging power factor operation except at high system voltage (say, 1.05 p.u. or above). Since the chance of requiring maximum MVAr generation at a time of high system voltage is remote, the limit line for this condition is not considered relevant.

It is usually sufficient to perform the leading power factor tap limit calculation for only two values of system voltage – say, high and nominal. A third calculation for low system voltage would reveal the maximum reactive absorption possible at a time of low system voltage, but as it is most unlikely that reactive absorption will be needed at such a time the limit line for this condition is not considered relevant.

Appendix A to Design Memorandum 099/61 recommends that, where generator transformer overfluxing imposes a limit, the performance chart should show the overfluxing limit for various values of generator terminal voltage. This differs from the recommendation in this Memorandum that each chart should relate to one terminal voltage only; it is considered inadvisable to show overfluxing limits for reduced terminal voltages on a chart drawn for, say, 1.0 p.u. terminal voltage because reduction in voltage also alters the rest of the chart (e.g. the practical stability limit moves to the right).

The procedure described in Design Memorandum 099/61 is useful as part of an investigation of overfluxing, leading to the determination of the normal terminal voltage required to avoid such a condition. The performance chart would then be constructed in detail, for that terminal voltage, in accordance with this Memorandum.

The number of lines on the chart could be further reduced by plotting separate charts for AVR and manual control. However, this is not recommended unless the presence of both control lines on one chart seriously impairs its intelligibility.

It is recommended that two separate charts should be plotted to show conditions at the generator terminals (LV chart) and at the HV side of the generator transformer (HV chart). (The equations of Appendix B allow for the LV metering point being on either side of the unit transformer.) While the planning engineer or system operation engineer might find it useful to have both HV and LV limit lines on a single chart, the station operator only requires information for the metering point which is used to monitor the performance of the generator. If, as is sometimes the case, the metering point is on the HV side of the generator transformer, there is no need to prepare an LV chart.

The recommended methods for presenting generator performance charts for the Type 1 and 2 generator arrangements, and the special case of the directly connected machine are summarized as follows:

5.1 Generators Having Transformers with On-load Taps (Type 1)

Two charts are required – one HV and one LV – unless there is no generator terminal metering, when the LV chart can be omitted.

Each chart should show operating limits for the following conditions:

Tap Position – Extreme negative tap (minimum turns ratio).
Terminal Voltage – 1.0 p.u. or nominal voltage.
System Voltage – (i) nominal; (ii) high*.
Control – (i) AVR; (ii) manual.

*Choice of high voltage should suit local conditions.

In general, limit lines will not be shown for a third (low) value of V_s nor for the tap limit for extreme positive tap. It is possible that additional charts may be required for alternative values of terminal voltage.

5.2 Generators Having Transformers with Off-load Taps (Type 2)

Two charts are required – one HV and one LV – unless there is no generator terminal metering, when the LV chart can be omitted.

Each chart should show operating limits for the following conditions:

Tap Position – Tap in normal use.
Terminal Voltage – Not specified (varies during operation).
System Voltage – (i) nominal; (ii) high*.
Control – (i) AVR; (ii) manual.

*Choice of high voltage should suit local conditions.

In general, limit lines will not be shown for a third (low) value of V_s. It is possible that additional charts may be required for alternative off-load tap positions.

5.3 Directly Connected Generators

Only one chart is required since HV and LV conditions are identical for a directly connected machine. The chart should show limits for the upper and lower extremes of system voltage which are likely in normal operation. If the resulting performance 'envelopes' are widely separated, the limits should also be drawn for an intermediate system voltage.

Charts for reactor-connected generators with generator terminal metering should be plotted as in 5.2, and those without terminal metering should be treated as directly connected generators of higher reactance.

7. REFERENCES

The following documents are referred to in the Memorandum and its appendixes:

Generation Design Circular No. 14, 'Automatic Voltage Regulators for AC Generators – VAr Limiters'.

Design Memorandum 099/61, 'Transformer Overfluxing'.

IEE Paper 4699P, 'Geometric Construction of the Stability Limits of Synchronous Machines', Proceedings Vol. 112, No. 5, May 1965.

Report PL–ST/28/72, 'Transient Stability Assessment of 500 MW Sets from System Post-Fault Infeeds'.

Comments by users on the contents of this Memorandum would be appreciated by the System Technical Engineer, Planning Department, CEGB Headquarters.

APPENDIX A

Symbols, Units and Sign Convention Used in the Appendices

The symbols, units and sign convention are listed below. The basic data, which should be assembled before a chart is drawn, is listed in Clause A.1, and the general symbols used in the equations are listed in Clause A.2. The sign convention which is used throughout the Appendices is shown in Clause A.3.

A.1 Symbols And Units Of Basic Data

The items marked * can be obtained from the National Data Catalogue.

* V_R - generator terminal rated voltage (volts)

* V_L - generator transformer rated L.V. voltage (p.u. on V_R volts base)

* V_N - nominal H.V. system voltage (volts)

* V_H - generator transformer H.V. open-circuit voltage on nominal tap with rated L.V. voltage applied (p.u. on V_N volts base)

V_M - maximum generator transformer internal voltage to avoid overfluxing [p.u. on V_L V_R volts base

$$= \frac{\text{max. flux density to avoid overfluxing (tesla)}}{\text{nominal flux density (tesla)}}]$$

* S_R, P_R - MVA and MW ratings of generator respectively (p.u. on 100 MVA base)

S_u, P_u, Q_u - MVA, MW and MVAr loadings of unit transformer (p.u. on 100 MVA base)

* S_T - MVA rating of generator transformer (p.u. on 100 MVA base)

* X_d - generator direct axis synchronous reactance (p.u. on 100 MVA base)

* X_T - generator transformer leakage reactance (values for various tap positions will be required) (p.u. on 100 MVA base)

* N - nominal generator transformer turns ratio

Eg_{min} - Generator open-circuit terminal voltage at minimum excitation (p.u. on V_R volts base)

Eg_{max} - Generator open-circuit terminal voltage at maximum excitation (p.u. on V_R volts base)

C_o - margin of excitation control system at zero MW output (p.u.)

C_F - margin of excitation control system at rated MW output (p.u.)

The following data is also required where applicable, but no symbol is included:-

Generator minimum MW output (p.u. on 100 MVA base)

A.V.R. Operating range (p.u. on V_R volts base)

* Generator Transformer Tapping range (p.u. on nominal turns ratio)

* MVAr limits due to excitation limiters

A.2 General Symbols And Units

V_T - generator terminal voltage (p.u. on V_R volts base)

V_1 - internal L.V. voltage of generator transformer (p.u. on V_R volts base)

V_S - H.V. system voltage (p.u. on V_N volts base)

S_M, P_M, Q_M - MVA, MW and MVAr flows respectively at the generator terminals (p.u. on 100 MVA base)

S_L, P_L, Q_L - MVA, MW and MVAr flows respectively at the L.V. side of the generator transformer (p.u. on 100 MVA base)

S_H, P_H, Q_H - MVA, MW and MVAr flows respectively on the H.V. side of the generator transformer (p.u. on 100 MVA base)

Q_T - MVAr loss in the generator transformer (p.u. on 100 MVA base)

N_n - generator transformer turns ratio at any position

n - generator transformer turns ratio at any position (p.u. on nominal turns ratio, $n = \frac{N_n}{N}$)

δ - generator rotor angle (degrees)

A.3 Sign Convention

The following sign convention is used throughout the Appendices:-

Generated and lagging MVAr are considered positive.

Absorbed and leading MVAr are considered negative.

APPENDIX B

General Methods of Chart Plotting

As discussed in Clause 3 the performance chart for any generator arrangement will be one of two types. Clauses B1, B2 and B3 describe how to plot charts for cases in which the generator terminal voltage (V_T) is constant; these should be used for generators connected through transformers with on-load tap changers. Clauses B4, B5 and B6 describe how to plot charts for cases in which V_T varies and should be used for generators connected through transformers with off-load taps.

The methods described are general. All possible limits of performance are included, as shown on Figure B1, and arrangements having unit transformers are studied. Thus, using these methods, charts can be plotted for any conditions of voltage, tap-position etc., for any generator connection arrangement. The recommended presentation of charts is discussed in Clause 5.

The method to be used for a directly connected generator is a special case of that for the arrangement where V_T remains constant. In practice, directly-connected machines may be connected to parts of the system where a variation of MVAr output will result in a change in the system voltage ($V_S = V_T$). Nevertheless, a chart drawn for constant V_T will demonstrate the area within which the generator may be safely operated even though the characteristics of the external system may prevent it reaching some of the limits shown. The chart should be constructed using the equations of B1 except for B1.?.

Reactor-connected generators can be treated in the same way if there is no generator terminal metering point (i.e. the reactor is included with the generator reactance). However, if the metering point is at the generator terminals, the chart must be drawn as for an off-load tap transformer arrangement with a tap ratio of 1.

For generators connected through generator transformers having no unit transformer, zero MW and MVAr loadings for the unit transformer should be included in the initial data. L.V. charts with respect to the generator terminals and the terminals of the generator transformer will be the same for these cases.

Charts relating to three points, the generator terminals and the transformer L.V. and H.V. terminals, are considered to enable charts to be drawn with respect to the applicable metering point. In clause 5 it is recommended that charts for the generator terminals and transformer HV should be provided.

Appendices C and D show worked examples of both types of chart. Appendices E and F show the derivation of general equations which are used in the following constructions.

A computer program has been developed by the South Eastern Region for plotting performance charts. There are several differences in the assumptions and equations used in the following methods and those used in the program, which are discussed in Appendix G. Figs. G1-G4 have been included to show computer-drawn charts for the worked examples of Appendices C and D. Comments on the charts are included in Appendix G.

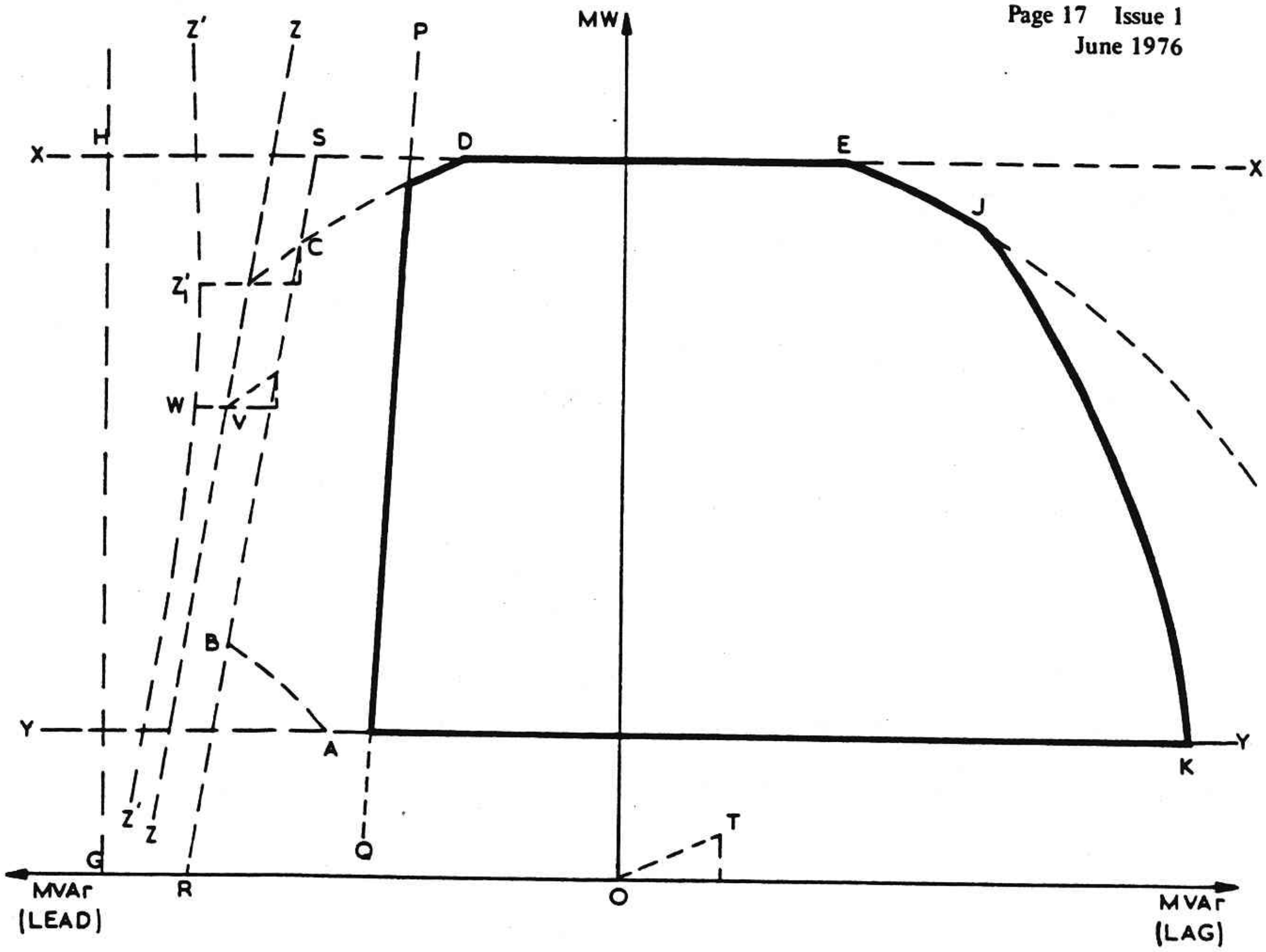


FIG. B1

B.1 L.V. Charts, With Respect To The Generator Terminals, For Cases In Which The Terminal Voltage Is Constant

The limit lines shown on Fig.B1 are referred to in this Appendix. The data listed in Appendix A should be assembled to enable the following constructions to be made:-

B.1.1 MW and MVAr Axes

The axes should be scaled in MW and MVAr for convenience.

NOTE:- In this Appendix calculations give results in p.u. on a 100 MVA base. Thus all results must be multiplied by 100 to obtain MW and MVAr values.

B.1.2 Rated MW Output Line

This line, XX, should be drawn parallel to the MVAr axis at the value of the rated MW output of the generator. The position of this line is independent of the system and terminal voltages.

B.1.3 Minimum MW Output Line

This line, YY, should be drawn parallel to the MVAr axis, at the value of minimum MW output of the machine. The position of YY is independent of the system and terminal voltages.

B.1.4 90° Rotor Angle Line

This line, GH, which is parallel to the MW axis, is located as follows:-

(a) Locate Point G

Length OG $= \dfrac{V_T^{\,2}}{X_d}$ and G lies on the zero MW line.

(b) Construct The 90° Rotor Angle Line

Through G draw line GH parallel to the MW axis. This cuts the rated MW line, XX, at H.

B.1.5 Practical Stability Limit Line

This line, RS, should be constructed as follows:-

(a) Locate Point R

$$GR = P_R.C_o$$

Point R lies on the zero MW line.

(b) Locate Point S

$$GS = P_R(1 + C_F)$$

Point S lies on the rated MW line, XX.

(c) Construct The Practical Stability Limit Line

Join points R and S to give the practical stability line.

Lines for AVR and manual control should appear on the same chart, see Clause 5, unless this would cause confusion.

B.1.6 Minimum Excitation Limit Line

This line, which passes through points A and B, has a circular locus having its centre at G and a radius of $\dfrac{V_T.Eg_{min}}{X_d}$. Point A lies on the minimum MW limit line, and point B lies on the practical stability limit line.

Lines for AVR and manual control should appear on the same chart, see Clause 5, unless this would cause confusion.

B.1.7 Rated Current Limit Line (at leading power factors)

This line, CD, shows the limit due to the current rating restriction of the generator or its transformer, whichever is the lower. If there is any doubt which rating will cause the limitation, both must be constructed. The locus of the limit imposed by the generator rating will be circular having its centre at O and a radius, equal to the machine MVA rating at the terminal voltage being considered, of $\underline{S_R.V_T}$

The limit imposed by the generator transformer should be constructed as follows.

With the generator absorbing MVAr, the maximum MVA flow in the transformer is on its H.V. side. Thus, although the locus of the line will be circular and have a radius equal to the rating of the generator transformer, at the system voltage being considered, of $\underline{S_T.V_S}/V_H$ the centre will not be at O as the reference for the rating is the H.V. side of the transformer. The centre of this locus should be located as follows:-

(a) Refer The Practical Stability Line To The H.V.

(i) Refer a point on the line RS to the L.V. side of the generator transformer, by subtracting the unit transformer MW and MVAr loading.

(ii) Through this point, draw a line ZZ parallel to RS. This is the practical stability line referred to the generator transformer L.V. side.

(iii) For a point, say V, on the line ZZ, calculate the generator transformer MVAr loss.

$$\text{Transformer MVAr loss,} \quad Q_T = \frac{X_T}{V_T^2} \left(P_L^2 + Q_L^2\right)$$

Subtracting this loss, point V gives an equivalent point W on the H.V. side limit line, which is moved horizontally to the left from V on the chart by the amount of the loss.

(iv) Repeat (iii) for several points on line ZZ, and through the points construct the line Z'Z' which is the practical stability line referred to the generator transformer H.V. side.

(b) Locate The Centre Of The Locus

To take account of the transformer MVAr loss with rated MVA on the H.V. side:-

(i) Locate the point Z_1' on the line Z'Z' which lies on a circle of centre O and radius, equal in magnitude to the rating of the generator transformer at the system voltage being considered, of $S_T \frac{V_S}{V_H}$. The point Z_1' represents the rated condition for the generator transformer in terms of the H.V. loading.

(ii) Refer the point Z_1' to its matching point on the generator terminal, C, by reversing the method described in B.1.7, (a) (i) to (iii) above.

(iii) The centre of the rated current line, T, should be located from O as C is located from Z_1' in B.1.7, (b) (ii) above.

(c) Construct the Rated Current Limit Locus

Point T is the centre of the circular locus which has a radius, equal in magnitude to the rating of the generator transformer at the system voltage being considered, of $S_T \frac{V_S}{V_H}$.

Points C and D lie on the locus, where it cuts the lines RS and XX respectively.

B.1.8 Generator Transformer Tap Limit Line

The equations of Appendix E should be used to calculate MVAr limits due to the restricted range of the generator transformer tap-change. For appropriate values of H.V. system voltage, tap position and generator terminal voltage, points on the limit line should be plotted for several values of MW load using Equation E3 of Appendix E.

Thus
$$Q_M = Q_u + \frac{V_T^2}{X_T} \pm \sqrt{\left(\frac{V_S V_L V_T}{n X_T V_H}\right)^2 - P_L^2}$$

The largest value of Q_M in each case should be ignored.

The line, PQ, should be drawn through the points calculated, to give tap limit line. For alternative values of V_s, n or V_T Clause B.1.8 above should be repeated using the revised values to give the alternative tap limit lines.

B.1.9 VAr Limit Lines

Any limits set on the MVAr output by under-excitation limiters should be shown if significantly different from the practical stability limit line.

B.1.10 Rated Current Line (at lagging power factors)

This limit can be imposed by the rating of the generator or by that of the generator transformer. If there is any doubt which rating will cause the limitation, both lines must be constructed.

The limit imposed by the generator rating has a circular locus, having its centre at O and a radius of $\frac{S_R V_T}{}$, the stator current rating expressed in MVA at the appropriate terminal voltage. This line will meet the rated MW line, XX, at E, and the minimum line, YY, at F (not shown on Fig B1).

The limit imposed by the generator transformer rating has a circular locus, having a radius of $S_T V_T / V_L$ the transformer current rating expressed in MVA at the appropriate terminal voltage, and a centre which is displaced from 0 by values of MW and MVAr equal to the loading of the unit transformer (the MVAr load is lagging and thus the centre is displaced to the right of 0). This limit is not shown on Fig. B1.

B.1.11 Maximum Excitation Limit Line

This line, JK, has a circular locus having its centre at G. The radius has a magnitude of

$$\frac{V_T Eg_{max}}{X_d} .$$

In Fig. B1 this limit line is shown to cut the rated current limit line at J, and the minimum MW limit line at K.

During the guarantee period, or if Eg_{max} is not known, the value of Eg_{max} must not exceed that for rated load and power factor.

B.1.12 Stator End Heating Limit Line

This limit, where it exists, will only be known as a result of specific tests.

B.1.13 Generator Transformer Overfluxing Limit Line

Individual points on this line should be plotted for several values of P_L using this equation.

$$Q_L = \frac{2 V_T}{X_T} \left[V_T - \sqrt{V_M V_L - \left(\frac{P_L X_T}{2V_T}\right)^2} \right]$$

This Equation is derived in Ref. 2 .

Through the points $[(P_L + P_u), (Q_L + Q_u)]$ draw the Generator Transformer Overfluxing Limit Line.

B.1.14 Outline Of The Chart

The most severe restrictions of all those calculated should be outlined, to give the operating chart for conditions at the generator terminals for the specific conditions of voltage etc. considered.

All construction lines should be removed to avoid confusion.

B.2 L.V. Charts, With Respect To The Transformer Terminals, For Cases In Which The Terminal Voltage Is Constant

This chart is similar in shape to that drawn with respect to the generator terminal. To obtain this chart the salient points of the chart for the generator terminals should be displaced to the left, horizontally, by the MVAr loading of the unit transformer and downwards, vertically, by the MW loading of the unit transformer.

Thus any point on this chart (P_L, Q_L) is equivalent to $[(P_M - P_u), (Q_M - Q_u)]$

B.3 H.V. Charts For Cases In Which The Terminal Voltage is Constant

The H.V. chart should be constructed from the L.V. chart constructed in Clause B.1. All the salient points on the L.V. chart should be related to the H.V. side of the generator transformer by subtracting at each point the values of unit transformer MW and MVAr load and the generator transformer MVAr loss. The MVAr flow on the H.V. side should be calculated using Equation E4 of Appendix E.

Typically a point (P_M, Q_M) on the L.V. chart will become point

$$\left\{ (P_M - P_u),\ \left[Q_M - Q_u - \frac{X_T}{{V_T}^2} \left(\overline{P_M - P_u}^{\,2} + \overline{Q_M - Q_u}^{\,2} \right) \right] \right\}$$

The H.V. chart will resemble the L.V. charts, but will be moved, effectively, to the left.

B.4 L.V. Charts, With Respect To The Generator Terminals, For Cases In Which The Terminal Voltage Varies

The value of V_T varies on this chart and thus the construction of several lines differs from that for cases with V_T constant. The range within which V_T can vary may impose extra limits on the operation of the generator.

The following constructions should be made:-

B.4.1 MW and MVAr Axes

See Clause B.1.1.

B.4.2 Rated MW Output Line

See Clause B.1.2.

B.4.3 Minimum MW Output Line

See Clause B.1.3.

B.4.4 90° Rotor Angle Line

As V_T varies, this line, GH, will not be vertical or straight. The line should be constructed as follows:-

(a) Locate Any Point on the Line

Locate any point on the line GH by using Equation F5 of Appendix F.

Thus for any value of P_M, $P_L = P_M - P_U$. $Q_M = Q_L + Q_u$

$$\therefore \quad Q_M = Q_u + \frac{X_d}{2(X_d + X_T)^2} \left(\frac{V_S\ V_L}{n V_H} \right)^2 \left\{ -1 \pm \sqrt{1 - \left[2\ \frac{P_L\ X_T}{X_d} \left(\frac{n V_H}{V_S V_L} \right)^2 (X_d + X_T) \right]^2} \right\}$$

This gives any point on the line (P_M, Q_M)

(b) Repeat (a) For Several Values of P_M

(c) Construct The 90° Rotor Angle Line

Join the points (P_M, Q_M) to construct the 90° rotor angle line. This line cuts the zero MW line at G and the rated MW at H.

B.4.5 Practical Stability Limit Line

(a) Locate Point R

See Clause B.1.5

(b) Locate Point S

From a point G' on the zero MW line, vertically below H, locate S such that $G'S = (1 + C_F)P_R$. S lies on the rated MW line, XX.

(c) Construct the Practical Stability Line

Join points R and S to give the practical stability line.

Lines for AVR and manual control should appear on the same chart, see Clause 6, unless this would cause confusion.

B.4.6 Minimum Excitation Limit Line

This line, which passes through points A and B, lies at a distance of $\frac{V_T . Eg_{min}}{X_d}$ from G. However, in this case V_T varies, and thus the co-ordinates of any point on this line should satisfy the Equation, F3 of Appendix F, for V_T. Thus each point on the locus should be calculated individually.

In general, a circle having a radius proportional to $V_T = 1.0$ p.u. should be drawn to give a pessimistic limit line. If this line imposes a limit on performance, then the points on the line should be plotted individually, taking account of the variation of V_T.

Lines for AVR and manual control should appear on the same chart, see Clause 6, unless this would cause confusion.

B.4.7 Rated Current Limit Line (at leading Power factors)

This line shows the limit due to the current rating restriction of the generator or its transformer, whichever is the lower. If the limit is imposed by the generator rating, then points C and D will lie on a line whose distance from O is $S_R . V_T$ the stator current rating at the appropriate terminal voltage. However, V_T varies and thus each point on the line should satisfy the Equation, F3 of Appendix F, for V_T.

In general a limit line should be constructed which has a circular locus, having its centre at O, and a radius of $S_R.V_T$ in which V_T is the terminal voltage at point G. This is calculated using Equation F7 of Appendix F, where $P_L = 0$.

This limit line will be pessimistic, as the machine will never operate at this terminal voltage. If this line imposes a limit on performance the points on the line should be plotted individually, taking account of the variation of V_T.

If, however, the limit is imposed by the generator transformer, the line should be constructed as follows:-

With the generator absorbing MVAr, the maximum MVA flow in the transformer is on its H.V. side. Thus, the points C and D will again lie on a circle, which has a radius equal to the rating of the generator transformer at the system voltage being considered. However, the centre will not be at O as the reference for the rating is the H.V. side of the transformer. The circle should be constructed as follows:-

(a) Locate Centre of Locus

The centre of the locus, point T, is displaced from O by the unit transformer MW and MVAr loadings, and the MVAr loss in the generator transformer, with rated MVA on its H.V. side.

The MVAr loss in the generator transformer with S_T on the H.V. side

$$= \frac{X_T}{V_1^2}\left(\frac{V_S S_T}{V_H}\right)^2$$

$$= X_T\left(\frac{n S_T}{V_L}\right)^2$$

Thus the co-ordinates of T are $\left\{ P_u, \left[Q_u + X_T\left(\frac{n S_T}{V_L}\right)^2 \right] \right\}$

(b) Construct Rated Current Limit Line

Construct the line which has a circular locus, centred on T, having a radius of $S_T.V_S/V_H$ points C and D lie on the line, where it cuts the lines RS and XX respectively.

B.4.8 Generator Transformer Tap Limit Line

For cases in which V_T varies this limit line is not applicable since V_T can be altered to vary MVAr flows at any particular tap position. (This applies to the case of a generator having a transformer with on-load taps if V_T is allowed to vary).

A restriction on the range of V_T may be imposed, however, but this is discussed in Clause B.4.14.

B.4.9 VAr Limit Lines

Any limits set on the MVAr output by under-excitation limiters should be shown in the appropriate MVAr position, if significantly different from the practical stability limit line.

B.4.10 Rated Current Line (at lagging power factors)

This limit can be imposed by the rating of the generator or by that of the generator transformer. If the limit is imposed by the generator rating, the line has a locus whose distance from 0 is equal to $S_R.V_T$.

V_T varies at each point on the line, and thus the co-ordinates of each point must satisfy the Equation, F3 of Appendix F, for V_T.

A circle of centre 0, and radius $S_R.V_T$ with V_T assumed to be 1 p.u. should be drawn to give a pessimistic limit line. If this line imposes a limit on performance, the points on the line should be plotted individually, taking account of the variation of V_T.

Similarly, if the limit is imposed by the generator transformer rating, the line will not be circular due to the variation of V_T.

However, a circle of radius $S_T \, V_T/_{V_L}$ with V_T assumed to be 1.0 p.u. having its centre displaced from 0 by the MW and MVAr loadings of the unit transformer, should be drawn to give a pessimistic limit line. If the line imposes a limit on performance, the points on the line should be plotted individually, taking account of the variation of V_T.

B.4.11 Maximum Excitation Limit Line

The position of this line is always such that its distance from G is

$$\frac{V_T Eg_{max}}{X_d} \quad .$$

For any particular value of V_T, the line has a circular locus. However, V_T varies and thus the co-ordinates of any point on this line should satisfy the Equation, F3 of Appendix F, for V_T.

In general, a circle having a radius proportional to $V_T = 1.0$ p.u. should be drawn to show a pessimistic limit. If this line will impose a limit on performance, then points on the line should be plotted individually, taking account of the variation of V_T.

During the guarantee period, or if Eg_{max} is not known, the value of Eg_{max} must not exceed that for rated load and power factor.

B.4.12 Stator End Heating Limit Line

See Section B.1.12.

B.4.13 Generator Transformer Overfluxing Limit Line

In general older transformers with cores of hot rolled steel will operate at lower flux densities and are unlikely to present an overfluxing problem. This will apply to most off-load tap transformers. However, if the limit is required, individual points on the line must be plotted for several values of P_L using the equation:-

$$Q_L = \frac{2V_T}{X_T}\left[V_T - \sqrt{V_M V_L - \left(\frac{P_L X_T}{2V_T}\right)^2}\,\right]$$

This equation is derived in Reference 2 .

V_T varies at each point on the line and thus the co-ordinates of each point must satisfy the Equation, F3 of Appendix F, for V_T.

B.4.14 Terminal Voltage Restrictions

The terminal voltage may be restricted by the AVR and auxiliaries. MVAr limits due to the maximum permissible range of terminal voltage for various values of P_M should be calculated using Equation F3 of Appendix F. The points found for the various values of P_M should be joined to show the limit due to the permissible range of terminal voltage.

B.4.15 Outline of the Chart

The most severe restrictions of all those calculated should be outlined, to give the operating chart for conditions at the generator terminal for the specific conditions considered.

All construction lines should be removed to avoid confusion.

B.5 L.V. Charts, With Respect to the Transformer Terminals, For Cases In Which The Terminal Voltage Varies

This chart is similar in shape to that drawn with respect to the generator terminals. To obtain this chart, the salient points of the chart for the generator terminals should be displaced to the left, horizontally, by the MVAr loading of the unit transformer, and downwards, vertically, by the MW loading of the unit transformer.

B.6 H.V. Charts, For Cases In Which The Terminal Voltage Varies

See Clause B.3. In calculating the generator transformer MVAr loss at each salient point on the L.V. chart, the value of V_T must first be calculated for each point individually using Equation F3 of Appendix F.

APPENDIX C

Worked Example – For a Case in which the Terminal Voltage is Constant

This example has been produced using the data, symbols, units and sign convention shown in Appendix A and the constructions outlined in Appendices B1 and B3. Figures C1 and C2 show the charts constructed for the Generator Terminals and Generator Transformer H.V. Terminals respectively.

The charts have been constructed for two values of H.V. system voltage, V_S, of 1.0 p.u. and 1.05 p.u. assuming in both cases a terminal voltage of V_T = 1.0 p.u.

C.1 Parameters

The generator which is considered is the Drakelow 'B' No. 5 Set. The data regarding this set is listed below.

The machine parameters are as follows:-

$S_R = 1.33$ $P_R = 1.20$

Min. MW Output = 0.55

$X_d = 0.978$ $V_R = 13.8$

Under-Excitation Limit at rated MW Output = -0.42

Under-Excitation Limit at zero MW Output = -0.77

A.V.R. Category = 1, when on automatic control.

$C_O = 0.1$ $C_F = 0.04$

The generator transformer parameters are as follows:-

$S_T = 1.25$ Tapping Range = $\pm$ 0.1

when n = 1.0, $X_T = 0.1340$

when n = 1.1, $X_T = 0.1374$

when n = 0.9, $X_T = 0.1412$

$V_L = 1.0$ $V_N = 275$ $V_H = 1.073$

The design flux density is not known.

The unit transformer loadings assumed are:-

$P_u = 0.08$ $Q_u = 0.04$

C.2 Construction of L.V. Chart, with Respect to the Generator Terminals

The steps follow those shown in Appendix B1 and the chart is shown in Figure C1.

C.2.1 MW and MVAr Axes

These are plotted showing MW and MVAr values. All the following calculations give answers in p.u. on a 100 MVA base initially. These have been multiplied by 100 to be shown on the chart.

C.2.2 Rated MW Output Line

Rated MW Output = 1.20 x 100

= 120 MW

This line, XX, is drawn parallel to the MVAr axis, at a value 120 MW.

C.2.3 Minimum MW Output Line

Minimum MW Output = 0.55 x 100

= 55 MW

This line, YY, is drawn parallel to the MVAr axis at a value of 55 MW.

C.2.4 90° Rotor Angle Line

The line, GH, is constructed as follows:-

(a) Locate Point G

$$\text{Length OG} = -\frac{1.0^2}{0.978} = 1.022$$

$\therefore$ OG = 1.022 x 100

= -102.2 MVAr

(b) Construct the 90° Rotor Angle Line

Line GH is drawn through point G, parallel to the MW axis cutting the line XX at H.

C.2.5 Practical Stability Limit Line

The line for AVR control only has been shown to avoid confusion with construction lines which are not removed in this example.

This line, RS, is constructed as follows:-

(a) Locate Point R

GR = 1.20 x 0.1

= 0.12

$\therefore$ Length GR = 0.12 x 100

= 12 MVAr

Point R lies on the zero MW line.

(b) Locate Point S

GS = 1.20 (1.0 + 0.04)

= 1.20 x 1.04

= 1.248

∴ Length GS = 1.248 x 100

= 124.8 MVA

Point S lies on the rated MW line, XX.

(c) Construct the Practical Stability Limit Line

This line is constructed by joining points R and S.

C.2.6 Minimum Excitation Limit Line

Eg_{min} is not known for this machine, and this line, therefore, has not been constructed.

C.2.7 Rated Current Limit Line (At leading power factors)

The MVA rating of the generator transformer is lower than that of the generator, and therefore this limit, line CD, is caused by the transformer. The line is constructed as follows:-

(a) Refer the Practical Stability Line to the H.V. Side

(i) A point on the line RS is referred to the L.V. side of the generator transformer by subtracting from it the unit transformer MW and MVAr loadings.

(ii) Line ZZ is drawn through the point to refer the whole line, RS, to the L.V. side of the transformer.

(iii) For four points on the line ZZ, the transformer MVAr loss is calculated, as shown in Table C1 below, to give four corresponding points on line Z'Z', which is the practical stability limit line referred to the H.V. side.

$$\text{MVAr loss} = 100 \cdot \frac{X_T}{V_T^2} \left(P_L^2 + Q_L^2\right)$$

For MVAr absorption conditions, assumed transformer tap is -0.1 p.u. and thus $X_T = 0.1412$. $V_T = 1.0$ p.u.

P_L	Q_L	P_L^2	Q_L^2	$P_L^2+Q_L^2$	MVAr Loss	100 P_H	100 Q_H
1.00	-0.75	1.00	0.563	1.563	22.1	100	-97.1
0.8	-0.785	0.64	0.616	1.256	17.7	80	-96.2
0.6	-0.82	0.36	0.672	1.032	14.6	60	-96.6
0.4	-0.85	0.16	0.723	0.883	12.5	40	-97.5

TABLE C1

(iv) Join the points, co-ordinates (P_H, Q_H), to give line Z'Z'.

(b) Locate the Centre of the Locus

(i) Locate the point Z_1' on the line Z'Z' which lies on the circle centred on O with a radius of $OZ_1' = 1.25 \times \frac{1.0}{1.073} \times 100$

$= \underline{116.5 \text{ MVA}}$

(For $V_S = 1.05$, $OZ_1'' = 1.25 \times \frac{1.05}{1.073} \times 100 = \underline{122.3 \text{ MVA}}$)

(ii) Refer Z_1 and Z_1" to the corresponding points C and C' on the line RS, by adding the transformer MVAr loss and the unit transformer MW and MVAr loadings onto the point Z_1'.

(iii) Locate point T, the centre of the rated current locus, from O as C was located from Z_1', and T' as C' was located from Z_1".

(c) Construct the Rated Current Limit Locus

With T as the centre construct the circle having a radius of $1.25 \times \frac{1.0}{1.073} \times 100$ (for $V_S = 1.0$ p.u.).

$= \underline{116.5 \text{ MVA}}$

(For $V_S = 1.05$, $OZ_1'' = \underline{122.3 \text{ MVA}}$)

Points C and D lie on the locus, where it cuts lines RS and XX respectively. Similarly, points C' and D' lie on the locus drawn for $V_S = 1.05$.

C.2.8 Generator Transformer Tap Limit Lines

Using Equation E3 of Appendix E, several points on the lines are calculated. From Equation E3

$$Q_M = Qu + \frac{V_T^2}{X_T} \pm \sqrt{\left(\frac{V_S V_L V_T}{n\ V_H X_T}\right)^2 - P_L^2}$$

In all cases the large positive root is ignored.

(a) For Extreme Negative Tap

(i) For the case of $V_S = 1.0$ p.u.,

$V_L = 1.0$, $V_T = 1.0$, $n = 0.9$, $V_H = 1.073$

$X_T = 0.1412$, $Qu = 0.04$

Then $\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right) = \left(\frac{1.0}{0.9.1.073.0.1412}\right)$

$= \frac{1.0}{0.1364}$

$= \underline{7.331}$

For various values of P_L, points on the line are calculated as shown in Table C2.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
P_L	$(\frac{V_S V_L V_T}{n\ X_T V_H})^2$	$(\frac{V_S V_L V_T}{n\ X_T V_H})^2 - P_L^2$	$\sqrt{col(3)}$	$(\frac{V_T^2}{X_T})$	Q_M	100 Q_M
1.2	53.74	52.30	7.232	7.082	-0.110	-11.0
1.0	53.74	52.74	7.262	7.082	-0.140	-14.0
0.8	53.74	53.10	7.287	7.082	-0.165	-16.5
0.6	53.74	53.38	7.306	7.082	-0.184	-18.4
0.4	53.74	53.58	7.320	7.082	-0.198	-19.8

TABLE C2

(ii) For the case of V_S = 1.05 p.u.,

V_L = 1.0, V_T = 1.0, n = 0.9, V_H = 1.073

X_T = 0.1412 and Qu = 0.04

Then $(\frac{V_S V_L V_T}{n\ X_T V_H}) = 7.331 \times 1.05$

$= \underline{7.698}$

For various values of P_L, points on the line are calculated as shown in Table C3 below.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
P_L	$(\frac{V_S V_L V_T}{n\ X_T V_H})^2$	$(\frac{V_S V_L V_T}{n\ X_T V_H})^2 - P_L^2$	$\sqrt{col(3)}$	$(\frac{V_T^2}{X_T})$	Q_M	100 Q_M
1.2	59.27	57.83	7.605	7.082	-0.483	-48.3
1.0	59.27	58.27	7.634	7.082	-0.512	-51.2
0.8	59.27	58.63	7.657	7.082	-0.535	-53.5
0.6	59.27	58.91	7.675	7.082	-0.553	-55.3
0.4	59.27	59.11	7.688	7.082	-0.566	-56.3

TABLE C3

(b) For Extreme Positive Tap

(i) For the case of V_S = 1.0 p.u.,

V_L = 1.0, V_T = 1.0, n = 1.1, V_H = 1.073

X_T = 0.1374 and Qu = 0.04

Then $(\frac{V_S V_L V_T}{n\ X_T V_H}) = \frac{1.0}{1.1.0.1374.1.073}$

$= \underline{6.166}$

The values of Q_M calculated for five values of P_L are shown in Table C4 below.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
P_L	$\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right)^2$	$\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right)^2 - P_L^2$	$\sqrt{col(3)}$	$\left(\frac{V_T^2}{X_T}\right)$	Q_M	100 Q_M
1.2	38.02	36.58	6.048	7.278	+1.270	+127.0
1.0	38.02	37.02	6.084	7.278	+1.234	+123.4
0.8	38.02	37.38	6.114	7.278	+1.204	+120.4
0.6	38.02	37.66	6.137	7.278	+1.181	+118.1
0.4	38.02	37.86	6.153	7.278	+1.165	+116.5

TABLE C4

(ii) For the case of V_S = 1.05 p.u.,

$$\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right) = 1.05 \times 6.166$$

$$= \underline{6.474}$$

The values of Q_M calculated for five values of P_L are shown in Table C5 below.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
P_L	$\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right)^2$	$\left(\frac{V_S V_L V_T}{n\ X_T V_H}\right)^2 - P_L^2$	$\sqrt{col(3)}$	$\left(\frac{V_T^2}{X_T}\right)$	Q_M	100 Q_M
1.2	41.91	40.47	6.362	7.278	+0.956	+95.6
1.0	41.91	40.91	6.396	7.278	+0.922	+92.2
0.8	41.91	41.27	6.424	7.278	+0.894	+89.4
0.6	41.91	41.55	6.446	7.278	+0.872	+87.2
0.4	41.91	41.75	6.462	7.278	+0.856	+85.6

TABLE C5

(c) Construct the Generator Transformer Tap Limit Lines

The transformer tap limit lines PQ, P'Q', P"Q" and P'"Q'", caused the limited tap-range, are drawn through the points calculated (P_M, Q_M). The extreme positive tap limit for V_S = 1.05 is shown although operation in this region with high system voltage is unlikely.

C.2.9 VAr Limit Lines

A straight line, MN, is drawn through the limits on performance caused by the under-excitation limiters.

At rated MW output the limit = -42 MVAr

At zero MW output the limit = -77 MVAr

C.2.10 Rated Current Line (at lagging power factors)

The limit in this case could be caused by the rating of the generator or its transformer and therefore both lines are drawn. The limit caused by the generator has a circular locus, centre O, and radius 133 MVA. The line meets XX at E and YY at F.

The limit caused by the transformer rating has a circular locus, with a radius of 125 MVA, centred on a point offset from O by the unit transformer MW and MVAr loadings. The line meets XX at E' and YY at F'.

C.2.11 Maximum Excitation Limit Line

E_{gmax} is not known for the machine, and thus this line, EK, has been constructed using the value of excitation which gives rated MVA at the rated p.f. of the machine.

C.2.12 Stator End Heating Limit Line

This limit is not known for this machine.

C.2.13 Generator Transformer Overfluxing Limit Line

The generator transformer design flux density is not known in this case, and this limit has not been constructed.

C.2.14 Outline of the Chart

The restrictions on performance calculated for V_S = 1.0 and V_S = 1.05 are outlined with heavy lines on Figure C1. Construction lines and other limits are shown although these should be removed normally.

C.3 Construction of the H.V. Chart

The H.V. chart is constructed by referring all the salient points on the L.V. chart, (1) to (11), to the H.V. side of the generator transformer as described in Appendix B3. Table C6 below shows the calculation of the various points.

Point	P_M	$P_L(=P_H)$	Q_M	Q_L	$P_L^2+Q_L^2$	$\frac{X_T}{V_T^2}(P_L^2+Q_L^2)$	Q_H
(1)	0.550	0.470	+0.865	+0.825	0.902	0.124	+0.701
(2)	0.550	0.470	-0.190	-0.230	0.274	0.039	-0.269
(3)	0.550	0.470	-0.555	-0.595	0.575	0.081	-0.676
(4)	0.815	0.735	-0.535	-0.575	0.871	0.123	-0.698
(5)	1.110	1.030	-0.445	-0.485	1.296	0.183	-0.668
(6)	1.200	1.120	-0.275	-0.315	1.353	0.191	-0.506
(7)	1.200	1.120	-0.110	-0.150	1.277	0.180	-0.330
(8)	1.200	1.120	+0.570	+0.530	1.535	0.211	+0.319
(9)	0.580	0.500	+0.870	+0.830	0.939	0.129	+0.701
(10)	0.900	0.820	-0.150	-0.190	0.706	0.100	-0.290
(11)	0.550	0.470	+0.875	+0.835	0.918	0.126	+0.709

TABLE C6

C.4 Comments on the Resulting Charts

C.4.1 L.V. Chart

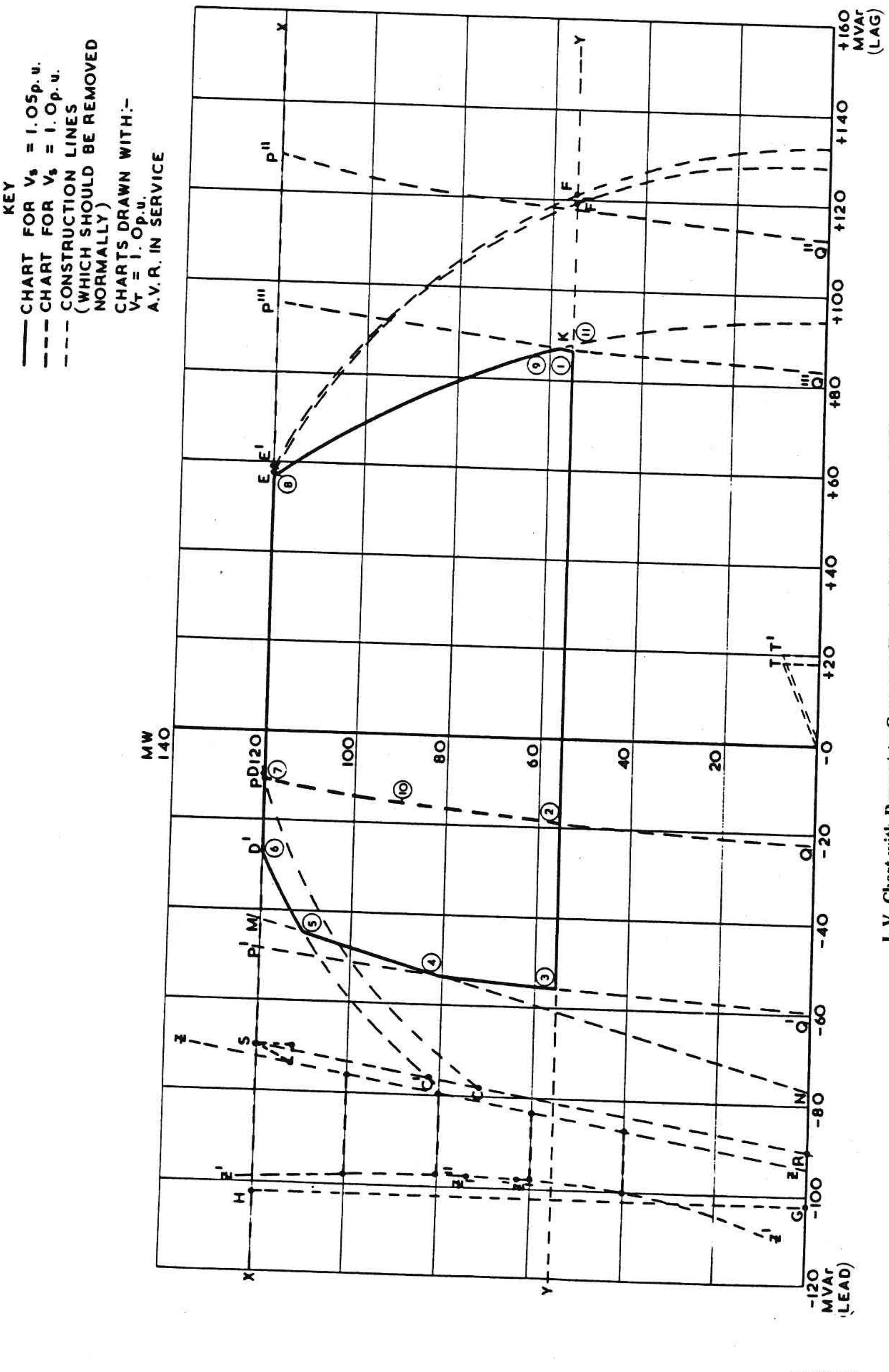
The range of MW operation is limited by the minimum permissible MW output and the rated MW output of the machine.

The lagging MVAr capability of the machine is bounded by the maximum excitation limit, which was assumed to be caused by that excitation which gives rated power output and p.f., except at minimum MW output when it would be limited by the tap-range of the transformer if the system voltage was 1.05 p.u. It can be seen that the MVA rating limit at lagging p.f.'s would be set by the generator transformer rating at a machine output of up to 100 MW and by the generator rating at an output of above 100 MW with a system voltage of 1.0 p.u.

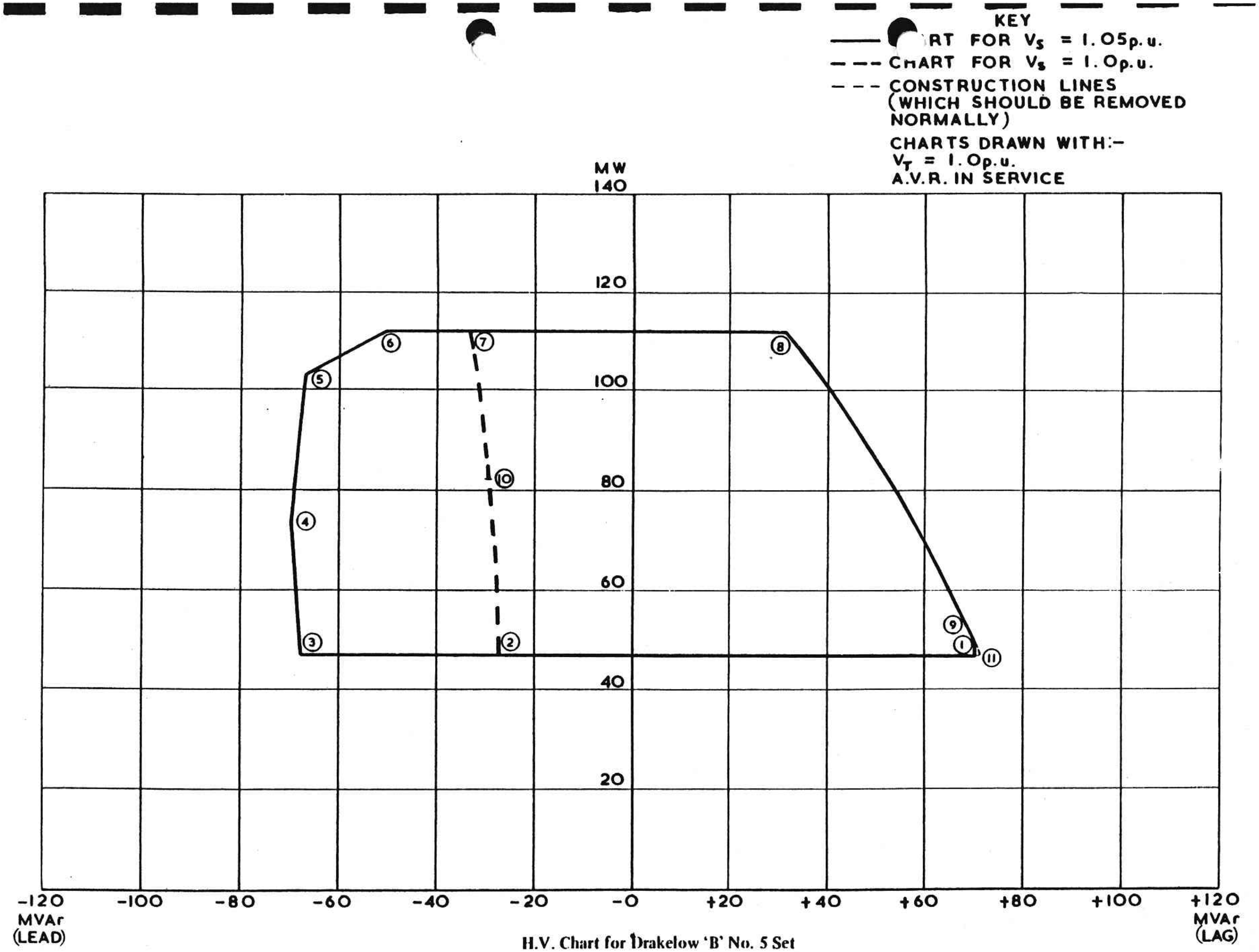
The leading MVAr capability varies as system voltage varies. With 1.0 p.u. system voltage there is a maximum absorption limit, 19 MVAr at minimum output, set by the generator transformer tap-range. At 1.05 p.u. system voltage the tap-range limits absorption with a machine output of up to 80 MW. Between 80 and 110 MW output the under-excitation limiter setting limits absorption; it can be seen that without the under-excitation limiter the tap-range would limit absorption, allowing only an additional 5 MVAr. Above 110 MW output, absorption is limited by the rating of the generator transformer.

C.4.2 H.V. Chart

The H.V. chart was constructed from the L.V. chart by displacing each point on the L.V. chart downwards by 8 MW, the assumed unit transformer loading, and to the left by the unit transformer reactive loading of 4 MVAr and the generator transformer series MVAr loss. The effect of the varying series loss in the transformer can be seen by the change in slope of the limit lines.



L.V. Chart with Respect to Generator Terminals for Drakelow 'B' No. 5 Set



H.V. Chart for Drakelow 'B' No. 5 Set

APPENDIX D

Worked Example – For a Case in which the Terminal Voltage Varies

This example has been produced using the data, symbols, units and sign convention advocated in Appendix A, and the constructions outlined in Appendices B.4 and B.6. Figures D.1 and D.2 show the chart constructed with respect to the generator terminals and generator transformer HV terminals respectively.

The charts have been constructed for two values of HV system voltage, 1.0 p.u. and 1.05 p.u. The machine is considered to operate with AVR control and the generator transformer on its nominal tap.

D.1 <u>Parameters</u>

The generator considered is the Blyth 'A' No. 3 set. The data is listed below. The symbols and units,which are used, are described in Appendix A .

The machine parameters are as follows:-

S_R = 1.50 P_R = 1.20

Minimum MW output = 0.60

X_d = 1.213 V_R = 13.8

Eg_{max} = Not Known Eg_{min} = 0.899

Under-excitation limit at rated MW output = -0.14

Under-excitation limit at zero MW output = -0.20

AVR Category = 1 for automatic control

C_o = 0.1 C_F = 0.04

There is a minimum terminal voltage restriction of V_T = 0.95 p.u.

It has been assumed that there is a maximum restriction, also, of 1.05 p.u.

The generator transformer parameters are:-

S_T = 1.45 Tapping Range = ± 0.03

On nominal tap,n = 1.0

X_T, on nominal tap = 0.092

V_L = 1.0 V_N = 66

V_H = 1.073

The design flux density is not known.

The unit transformer loadings assumed are:-

P_u = 0.08 Q_u = 0.04

D.2 Construction of the LV Chart, With Respect to the Generator Terminals

The steps follow those shown in Appendix B.4, and this chart is shown in Figure D.1.

D.2.1 MW and MVAr Axes

These are scaled in MW and MVAr values. All the following calculations give answers in p.u. on a 100 MVA base initially. These have been multiplied by 100 to be shown on the chart.

D.2.2 Rated MW Output Line

Rated MW Output = 1.20 x 100 = 120 MW

This line, XX, is drawn parallel with the MVAr axis at a value of 120 MW.

D.2.3 Minimum MW Output Line

Minimum MW Output = 0.60 x 100 = 60 MW

The line, YY, is drawn parallel to the MVAr axis at a value of 60 MW.

D.2.4 90° Rotor Angle Line

This line, GH, is constructed as follows:-

(a) Locate Any Point on the Line

From Equation F5 of Appendix F,

$$Q_M = Q_u + \frac{X_d}{2(X_d + X_T)^2}\left(\frac{V_S\,V_L}{nV_H}\right)^2\left\{-1 \pm \sqrt{1 - \left[\frac{2P_L\,X_T}{X_d}\left(\frac{n\,V_H}{V_S\,V_L}\right)^2(X_d + X_T)\right]^2}\right\}$$

$$Q_u = \underline{+0.04}$$

$$\frac{X_d}{2\,(X_d + X_T)^2} = \frac{1.213}{2(1.213 + 0.092)^2} = \underline{0.356}$$

For $V_s = 1.0$

$$\left(\frac{V_S\,V_L}{nV_H}\right)^2 = \left(\frac{1.0\ .\ 1.0}{1.0\ 1.075}\right)^2 = \underline{0.869}$$

For $V_s = 1.05$

$$\left(\frac{V_S\,V_L}{nV_H}\right)^2 = \left(\frac{1.05\ .\ 1.0}{1.0\ .\ 1.073}\right)^2 = \underline{0.958}$$

For $V_s = 1.0$

$$\left[\frac{2X_T}{X_d}\left(\frac{n' V_H}{V_s\ V_L}\right)^2 (X_d + X_T)\right]^2 = \frac{2.0 \ . \ 0.92^2}{1.213 \ . \ 0.356 \ . \ (0.869)^2} = \underline{0.052}$$

For $V_s = 1.05$

$$\left[\frac{2X_T}{X_d}\left(\frac{n\ V_H}{V_S\ V_L}\right) (X_d + X_T)\right]^2 = \frac{2.0 \ . \ 092^2}{1.213 \ . \ 0.356 \ . \ (0.958)^2} = \underline{0.043}$$

Various values of P_L can now be substituted in Equation F.5 to locate points on the line.

Substituting in Equation F.5

For $V_S = 1.0$

$$Q_M = + 0.04 + (0.356)\ (0.869)\ \{-1 \pm \sqrt{1 - 0.052\ P_L^2}\}$$

$$= 0.04 + 0.309\ \{-1 \pm \sqrt{1 - 0.052\ P_L^2}\}$$

$$\therefore \quad \underline{Q_M = 0.269 \pm 0.309 \sqrt{1 - 0.052\ P_L^2}}$$

For $V_S = 1.05$

$$Q_M = + 0.04 + (0.356)\ (0.958)\ \{- 1 \pm \sqrt{1 - 0.043\ P_L^2}\}$$

$$Q_M = 0.04 + 0.341\ \{- 1 \pm \sqrt{1 - 0.043\ P_L^2}\}$$

$$\therefore \quad \underline{QM = - 0.301 \pm 0.341 \sqrt{1 - 0.043\ P_L^2}}$$

(b) Calculation of P_M and Q_M for 8 Values of P_L

Values of Q_M can now be calculated for various values of P_L. In all cases the largest positive value of Q_M is ignored.

(i) For $V_S = 1.0$

P_L	P_M	P_L^2	$0.052P_L^2$	$1-0.052P_L^2$	$\sqrt{1-0.052P_L^2}$	$0.309 \times \sqrt{1-0.052P_L^2}$	Q_M	$100Q_M$
0	0.08	0	0	1.0	1.0	0.309	-0.578	-57.8
0.2	0.28	0.04	0.002	0.998	0.999	0.309	-0.578	-57.8
0.4	0.48	0.16	0.008	0.992	0.996	0.308	-0.577	-57.7
0.6	0.68	0.36	0.019	0.981	0.991	0.306	-0.575	-57.5
0.8	0.88	0.64	0.033	0.967	0.983	0.304	-0.573	-57.3
1.0	1.08	1.00	0.052	0.948	0.974	0.301	-0.570	-57.0
1.2	1.28	1.44	0.075	0.925	0.962	0.297	-0.566	-56.6
1.4	1.48	1.96	0.102	0.898	0.948	0.293	-0.562	-56.2

TABLE D.1

(ii) For $V_S = 1.05$

P_L	P_M	P_L^2	$0.043P_L^2$	$1-0.043P_L^2$	$\sqrt{1-0.043P_L^2}$	$0.341 \times \sqrt{1-0.043P_L^2}$	Q_M	$100Q_M$
0	0	0	0	1.0	1.0	0.341	-0.642	-64.2
0.2	0.28	0.04	0.002	0.998	0.999	0.341	-0.642	-64.2
0.4	0.48	0.16	0.007	0.993	0.997	0.340	-0.641	-64.1
0.6	0.68	0.36	0.015	0.984	0.992	0.338	-0.639	-63.9
0.8	0.88	0.64	0.028	0.972	0.986	0.336	-0.637	-63.7
1.0	1.08	1.00	0.043	0.957	0.978	0.333	-0.634	-63.4
1.2	1.28	1.44	0.062	0.938	0.969	0.330	-0.631	-63.1
1.4	1.48	1.96	0.084	0.916	0.957	0.327	-0.628	-62.8

TABLE D.2

(c) Construct the 90° Rotor Angle Line

The points (P_M, Q_M) are joined to show the 90° Rotor Angle Line for the two cases, $V_S = 1.0$ and $V_S = 1.05$. For $V_S = 1.0$ G_1 lies on the zero MW line and H_1 lies on the rated MW output line. For $V_S = 1.05$, G_2 lies on zero MW line and H_2 lies on the rated MW output line.

D.2.5 Practical Stability Limit Line

The line for AVR control only has been shown to avoid confusion with construction lines which have not been removed in this example.

(a) Locate Point R

(i) For $V_S = 1.0$

$G_1 R_1 = + 1.20 \times 0.1 \times 100 =$ +12 MVAr

Point R_1 lies on the Zero MW line

(ii) For $V_S = 1.05$

$G_2 R_2 = + 1.20 \times 0.1 \times 100 =$ +12 MVAr

Similarly, R_2 lies on the Zero MW line.

(b) Locate Point S

(i) For $V_S = 1.0$

$$G_1' S_1 = (1 + 0.04)\ 1.20 \times 100 = \underline{124.8 \text{ MVA}}$$

S_1 lies on the line XX.

(ii) For V_S 1 1.05

$$G_2' S_2 = (1 + 0.04)\ 1.20 \times 100 = \underline{124.8 \text{ MVA}}$$

Similarly, S_2 lies on the line XX.

(c) Construct the Practical Stability Limit Line

Construct lines $R_1 S_1$ and $R_2 S_2$ to give the practical stability limit lines for $V_S = 1.0$ and $V_S = 1.05$ respectively.

D.2.6 Minimum Excitation Limit Line

The line for AVR control only has been shown to avoid confusion with construction lines which have not been removed in this example.

(a) Construct Pessimistic Line Using $V_T = 1.0$

$$\text{Radius} = \frac{V_T\ Eg_{min}}{X_d} = \frac{1.0.0.899 \times 100}{1.213} = 0.74 \times 100 = \underline{74 \text{ MVA}}$$

Construction of circles $A_1' B_1'$ and $A_2' B_2'$ having radii of 74 MVA and centred on G_1 and G_2 respectively shows that the lines could cause a limitation on performance, as the lines cut the practical stability limit line above the minimum MW output line.

(b) Construction of Accurate Limit Lines

(i) Lines of Constant V_T

Lines of constant V_T are plotted on the section of the chart where this limit occurs. In this example lines have been drawn for only two values of V_T, 1.0 p.u. and 0.95 p.u.

From Equation F1

$$V_T^4 - V_T^2 \left[2Q_L X_T + \left(\frac{V_S V_L}{n V_H} \right)^2 \right] + X_T^2 \quad (Q_L^2 + P_L^2) = 0$$

Solving for Q_L

$$Q_L = \frac{V_T^2}{X_T} \pm \sqrt{\frac{V_T^2}{X_T^2} \left(\frac{V_S V_L}{n\ V_H} \right)^2 - P_L^2}$$

For V_S = 1.0

$$\left(\frac{V_S\ V_L}{n\ V_H}\right)^2 = \left(\frac{1.0}{1.0} \cdot \frac{1.0}{1.073}\right)^2 = \underline{0.869}$$

$$X_T = 0.092$$

$$\therefore\ Q_L = \frac{V_T^2}{0.092} \pm \sqrt{V_T^2 \cdot 102.8 - P_L^2}$$

In all cases, the large positive root is ignored.

V_T	P_L	P_L^2	$\frac{V_T^2}{0.092}$	$102.8V_T^2$	$102.8V_T^2 - P_L^2$	$\sqrt{102.8V_T^2 - P_L^2}$	Q_L	Q_M	100 P_M	100 Q_M
1.0	0	0	10.88	102.8	102.8	10.14	0.74	0.78	+ 8.0	+78.0
1.0	1.0	1.00	10.88	102.8	101.8	10.09	0.79	0.83	+108.0	+83.0
0.95	0	0	9.80	92.8	92.8	9.62	0.18	0.22	+ 8.0	+22.0
0.95	1.0	1.00	9.80	92.8	91.8	9.58	0.22	0.26	+108.0	+26.0

TABLE D.3

0.95 p.u. is the minimum limit of V_T. It can be seen from the co-ordinates of points on this line that the minimum excitation limit cannot cause a restriction more severe than the minimum terminal voltage restriction when V_S = 1.0 p.u. Thus, the accurate line has not been constructed.

For V_S = 1.05

$$\left(\frac{V_S\ V_L}{n\ V_H}\right)^2 = \left(\frac{1.05\ 1.0}{1.0\ 1.073}\right)^2 = 0.958$$

$$X_T = 0.092$$

$$\therefore\ Q_L = \frac{V_T^2}{0.092} \pm \sqrt{113.5\ V_T^2 - P_L^2}$$

V_T	P_L	P_L^2	$\frac{V_T^2}{0.092}$	$113.5V_T^2$	$113.5V_T^2 - P_L^2$	$\sqrt{113.5V_T^2 - P_L^2}$	Q_L	Q_M	100 P_M	100 Q_M
1.0	0	0	10.88	113.5	113.5	10.65	+0.23	+0.27	+ 8.0	+27.0
1.0	1.0	1.0	10.88	113.5	112.5	10.6	+0.28	+0.32	+108.0	+32.0
0.95	0	0	9.80	102.5	102.5	10.1	-0.3	-0.26	+ 8.0	-26.0
0.95	1.0	1.0	9.80	102.5	101.5	10.6	-0.26	-0.22	+108.0	-22.0

TABLE D.4

Plotting the line for V_T = 0.95 and V_S = 1.05, it can be seen that the minimum excitation limit can only cause a limit in the region of V_T = 0.95 p.u. For V_T = 0.95 p.u., Radius of limit $= \frac{0.899}{1.213} \times 0.95 \times 100 =$ 70.3 MVA

Draw the arc A_2 B_2 centred on G_2 having a radius of 70.3. This line applies for $V_S = 1.05$ and $V_T = 0.95$. From this arc it can be seen that the minimum excitation limit will not cause a restriction on performance more severe than the minimum terminal voltage restriction of $V_T = 0.95$ p.u.

D.2.7 Rated Current Limit Line (at leading power factors)

In this case the limit is imposed by the rating of the generator transformer.

(a) Locate Centre of Locus

The centre is displaced from O by the MW and MVAr loadings of the unit transformer and by the MVAr loss in the generator transformer.

MVAr loss in generator transformer, $X_T \left(\frac{n\ S_T}{V_L}\right)^2$,

$= 0.092 \left(\frac{1.0\ .\ 1.45}{1.0}\right)^2$

$= 0.194$

∴ The co-ordinates of T are +8.0 MW, +23.4 MVAr.

(b) Construct Rated Current Limit Line

(i) For $V_S = 1.0$

The line has a circular locus, centred on T and having a radius of $1.45\ .\ \frac{1.0}{1.073} \times 100 =$ 135 MVA

The line cuts R_1 S_1 at C_1 and XX at D_1

(ii) For $V_S = 1.05$

The line has a circular locus, centred on T and having a radius of $\frac{1.45}{1.073}\ .\ 1.05 \times 100 =$ 142 MVA

The line cuts R_2 S_2 at C_2 and XX at D_2

D.2.8 Generator Transformer Tap Limit Line

For cases where V_T varies, this line is not applicable (see Appendix B Clause B.4.8).

D.2.9 VAr Limit Lines

A straight line, MN, is drawn through the limit set on the under-excitation limiters.

At rated MW output, limit $= -0.14 \times 100 =$ -14.0 MVAr
At zero MW output, limit $= -0.20 \times 100 =$ -20.0 MVAr

D.2.10 Rated Current Line (at lagging power factors)

(a) Comparison of Limits Caused by The Ratings of the Generator and Generator Transformer

It is not obvious which rating, that of the generator or that of its transformer, causes the limit and thus both are shown initially for $V_T = 1.0$.

For the generator, line E'F' is constructed as the arc of the circle centre at O and radius of 1.50 x 1.0 x 100 = 150 MVA.

For the generator transformer, line E"F" is constructed as the arc of the circle which has its centre offset from O by the MW and MVAr loadings of the unit transformer and a radius of 1.45 . 1.0 x 100 = 145 MVA. It can be seen that the generator rating causes the limit of performance.

To plot the line accurately, lines of constant V_T in the region of the line are calculated. Only the line for $V_S = 1.0$ is constructed as operation in this region at high system voltage is unlikely as the assumed maximum terminal voltage of 1.05 p.u. would have to be exceeded.

(b) Calculation of the Accurate Limit Line

(i) Lines of Constant V_T

Lines of constant V_T are plotted on the part of the chart where the limit occurs, which satisfy Equation F.3 of Appendix F. Only two points on each line have been calculated as the lines are straight. In some cases the lines may not be straight, in which case more points should be plotted.

The method used is described in Clause D.2.6 (b) (i).

For $V_S = 1.0$

V_T	P_L	P_L^2	$\frac{V_T^2}{0.092}$	$102.8V_T^2$	$102.8V_T^2 - P_L^2$	$\sqrt{102.8V_T^2 - P_L^2}$	Q_L	Q_M	100 P_M	100 Q_M
1.0	0	0	10.88	102.8	102.8	10.14	0.74	0.78	+ 8.0	+ 78.0
"	1.0	1.00	10.88	102.8	101.8	10.09	0.79	0.83	+108.0	+ 83.0
1.05	0	0	12.00	113.5	113.5	10.65	1.35	1.39	+ 8.0	+139.0
"	1.0	1.00	12.00	113.5	112.5	10.60	1.40	1.44	+108.0	+144.0
1.01	0	0	11.10	104.8	104.8	10.22	0.88	0.92	+ 8.0	+ 92.0
"	1.0	1.00	11.10	104.8	103.8	10.18	0.92	0.96	+108.0	+ 96.0
1.02	0	0	11.30	106.7	106.7	10.30	1.00	1.04	+ 8.0	+104.0
"	1.0	1.00	11.30	106.7	105.7	10.25	1.05	1.09	+108.0	+109.0
1.03	0	0	11.58	109.5	109.5	10.45	1.13	1.17	+ 8.0	+117.0
"	1.0	1.00	11.58	109.5	108.5	10.40	1.18	1.22	+108.0	+122.0
1.04	0	0	11.75	111.5	111.5	10.55	1.20	1.24	+ 8.0	+124.0
"	1.0	1.00	11.75	111.5	110.5	10.50	1.25	1.29	+108.0	+129.0

TABLE D.5

For $V_S = 1.05$

V_T	P_L	P_L^2	$\frac{V_T2}{0.092}$	$113.5V_T^2$	$113.5V_T^2 - P_L^2$	$\sqrt{113.5V_T^2 - P_L^2}$	Q_L	Q_M	100 P_M	100 Q_M
1.0	0	0	10.88	113.5	113.5	10.65	+0.23	+0.27	+ 8.0	+ 27.0
"	1.0	1.0	10.88	113.5	112.5	10.6	+0.28	+0.32	+108.0	+ 32.0
1.05	0	0	11.98	125.2	125.2	11.18	+0.82	+0.86	+ 8.0	+ 86.0
"	1.0	1.0	11.98	125.2	124.2	11.14	+0.86	+0.90	+108.0	+ 90.0

TABLE D.6

(ii) Radius of Limit Line for the Various Values of V_T

V_T	$S_R \cdot V_T$
1.0	1.50
1.01	1.515
1.02	1.53
1.03	1.545
1.04	1.560
1.05	1.575

TABLE D.7

(iii) Construction of Limit Line

The points of intersection of the constant V_T lines and the circles of radius S_R V_T centred on O are found and the line, EF, drawn through them.

D.2.11 Maximum Excitation Limit Line

The maximum excitation is not known in this case, therefore the line through the point E is constructed, taking account of the variation of V_T, as this line will constitute a limit on performance. Again only the line for V_S = 1.0 is plotted.

The length G,E = 1.916

$$\text{Radius} = \frac{Eg_{max}\, V_T}{X_d}$$

V_T	Radius
1.006	1.916
1.01	1.92
1.02	1.94
1.03	1.96
1.04	1.98
1.05	2.0

TABLE D.8

Through the points of intersection of the circles drawn with the radii calculated and the appropriate lines of constant V_T, the line EK is drawn.

D.2.12 Stator End Heating Limit Line

This limit is not known for this machine.

D.2.13 Generator Transformer Overfluxing Limit Line

The generator transformer design flux density is not known in this case, and thus this limit cannot be constructed.

D.2.14 Terminal Voltage Restrictions

The terminal voltage cannot fall below 0.95 p.u. Points on this line have been calculated in Clause D.2.6 (b) (i) for system voltage of 1.0 p.u. and 1.05 p.u. These lines are plotted and shown as P_1 Q_1 and P_2 Q_2 respectively.

It has been assumed that V_T cannot rise above 1.05 p.u. Plotting the line for V_T = 1.05 p.u. and V_S = 1.05 p.u. (See Table D6) shows that this restriction causes a limit on performance when V_S = 1.05 p.u.

D.2.15 Outline of the Chart

The restrictions on performance calculated for V_S = 1.0 and V_S = 1.05 are outlined with heavy lines on Figure D.1. Construction lines and other limit lines are shown although these should be removed normally.

D.3 Construction of the HV Chart

The HV chart is constructed by referring points on the LV chart, (1) to (12) in this case, to the HV terminals of the generator transformer as described in Appendix B.5. Tables D9 and D10 below show the calculation of the various points.

(a) Calculation of V_T at Points on the LV Chart

Using Equation F3 of Appendix F, V_T can be found for the values of V_S, P_L and Q_L at each point.

Point	V_S	P_M	P_L (= P_H)	Q_M	Q_L	V_T
(1)	1.0	0.60	0.52	1.32	1.28	1.045
(2)	1.05	0.60	0.52	0.84	0.80	1.05
(3)	1.0	0.60	0.52	0.24	0.20	0.95
(4)	1.05	0.60	0.52	-0.17	-0.21	0.955
(5)	1.05	0.90	0.82	-0.155	-0.195	0.955
(6)	1.05	1.20	1.12	-0.14	-0.18	0.955
(7)	1.0	1.20	1.12	0.26	0.22	0.95
(8)	1.05	1.20	1.12	0.89	0.85	1.05
(9)	1.0	1.20	1.12	0.91	0.87	1.005
(10)	1.0	0.90	0.82	1.16	1.12	1.03
(11)	1.05	0.90	0.82	0.88	0.84	1.05
(12)	1.0	0.90	0.82	0.25	0.21	0.95

TABLE D.9

(b) Calculation of Points on the HV Chart

Knowing the value of V_T at each point on the LV chart the corresponding points on the HV chart are found as described in Appendix B.3. Table D.10 below shows the calculation of the various points.

Point	V_T	P_L (= P_H)	Q_L	$P_L^2 + Q_L^2$	$\frac{X_T}{V_T^2}(P_L^2 + Q_L^2)$	Q_H
(1)	1.045	0.52	1.28	1.91	0.16	1.12
(2)	1.05	0.52	0.80	0.91	0.08	0.72
(3)	0.95	0.52	0.20	0.31	0.03	0.17
(4)	0.955	0.52	-0.21	0.31	0.03	-0.24
(5)	0.955	0.82	-0.195	0.71	0.07	-0.265
(6)	0.955	1.12	-0.18	1.31	0.13	-0.31
(7)	0.95	1.12	0.22	1.30	0.13	0.09
(8)	1.05	1.12	0.85	1.98	0.17	0.68
(9)	1.005	1.12	0.87	2.01	0.18	0.69
(10)	1.03	0.82	1.12	1.93	0.17	0.95
(11)	1.05	0.82	0.84	1.38	0.12	0.72
(12)	0.95	0.82	0.21	0.72	0.07	0.14

TABLE D.10

D.4 Comments on the Resulting Charts

D.4.1 L.V. Chart

It was found necessary to construct lines of constant terminal voltage at several points on the chart. Although it has not been suggested in Appendix B, it might be worthwhile in some cases plotting lines of constant V_T, using Equation F3 of Appendix F, across the chart before constructing limit lines. However, it is difficult to decide beforehand whether this would be beneficial.

The range of MW operation is limited by the minimum permissible MW output and the rated MW output of the machine.

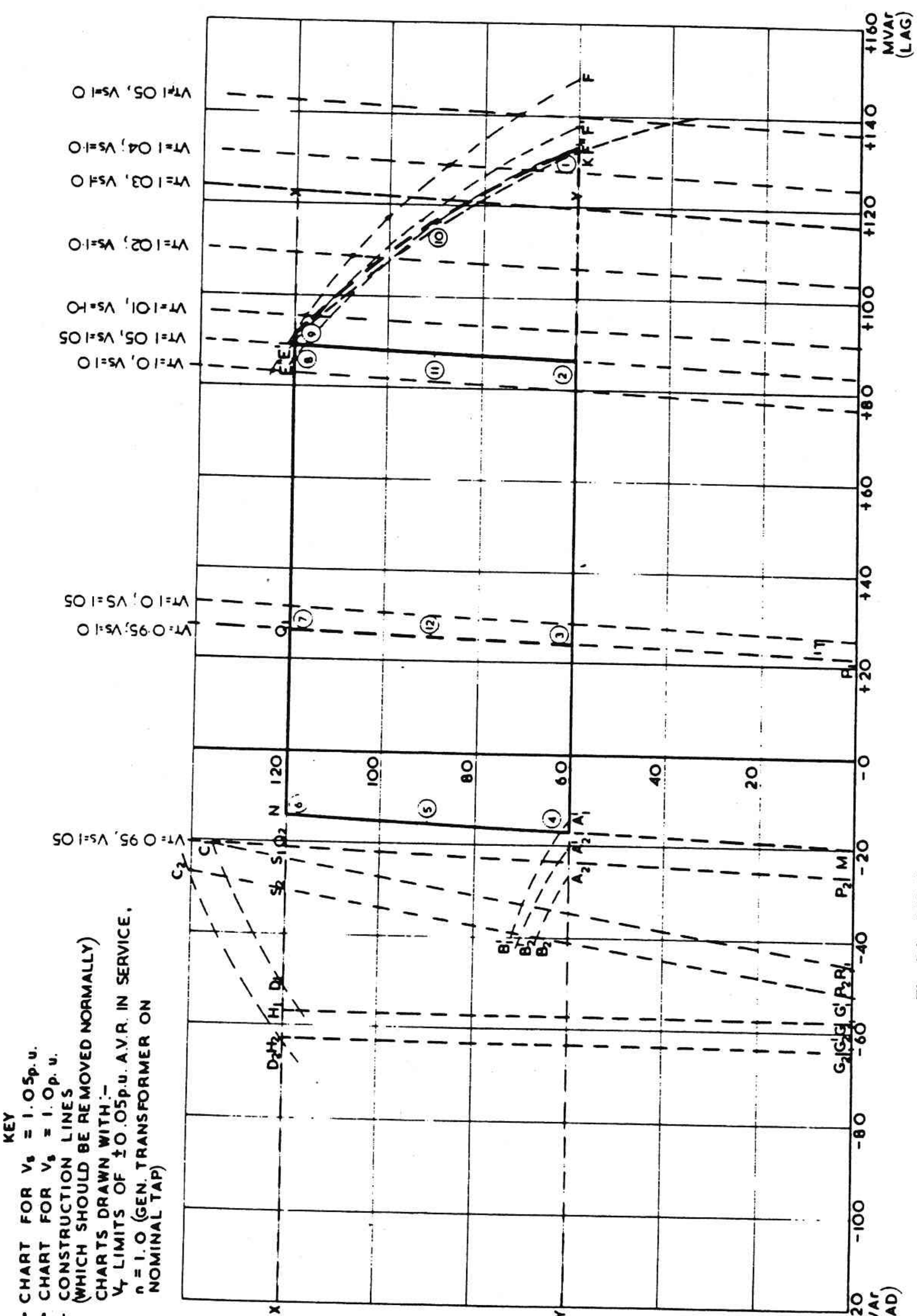
The lagging MVAr capability of the machine is limited by the maximum excitation limit (assumed to be equal to that which gives rated power output and p.f. conditions) at 1.0 p.u. system voltage. With 1.05 p.u. system voltage the MVAr generation is limited by the assumed 1.05 p.u. maximum limit of terminal voltage.

At 1.0 p.u. system voltage it is not possible to absorb MVAr, the machine being constrained to generate at least 24 MVAr at any MW output to avoid the terminal voltage falling below the 0.95 p.u. minimum permissible value. At a system voltage of 1.05 p.u. it can be seen that the minimum terminal voltage restriction would allow about 8 MVAr additional absorption capability if the under-excitation limiter setting was increased.

The range of operation would be altered by changing the transformer tap. In this example the transformer was assumed to operate on nominal tap.

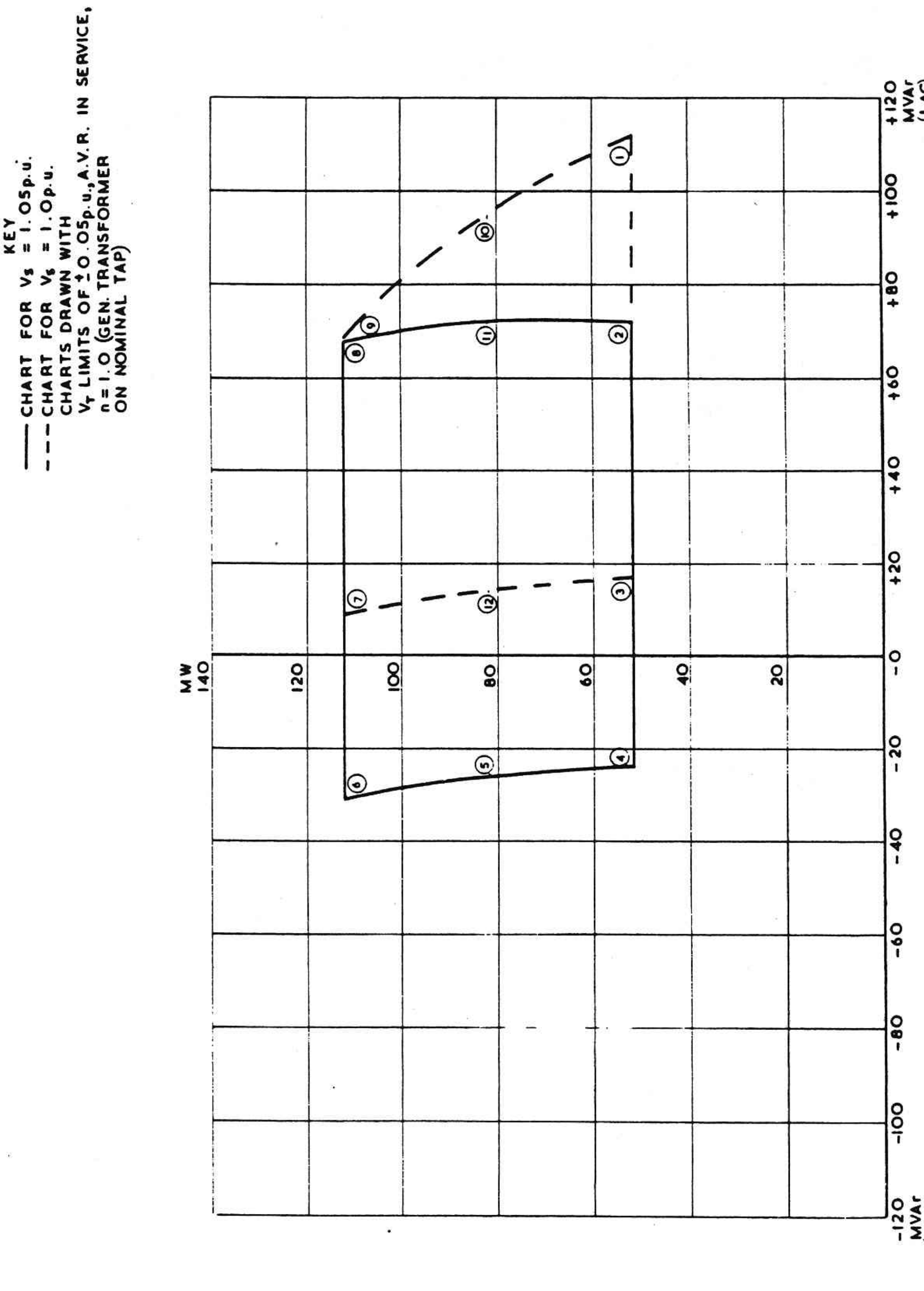
D.4.2 H.V. Chart

The H.V. chart was constructed from the L.V. chart by moving each point downwards by 8 MW, the assumed unit transformer loading, and to the left by the unit transformer reactive loading of 4 MVAr and the generator transformer series reactive loss. The effect of the varying series loss of the transformer can be seen by the change in slope of the limit lines.



93/11647A

Fig. D1 LV Chart with Respect to Generator Terminals for Blyth 'A' No. 3 Set



'93/11648

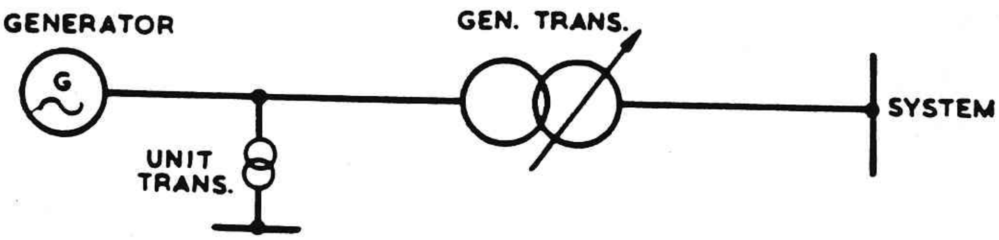
Fig. D2 HV Chart for Blyth 'A' No. 3 Set

APPENDIX E

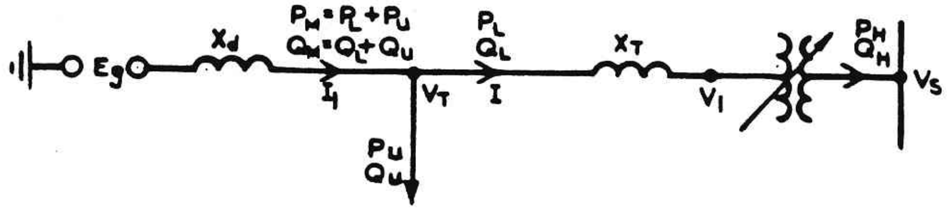
General Equations for a Generator Having a Transformer with On-load Taps

Equations to be used in the plotting of performance charts, for generators connected through transformers having on-load taps, are derived in this Appendix. The general case of a generator with a unit transformer connected is considered. The terminal voltage of the generator is assumed to be constant.

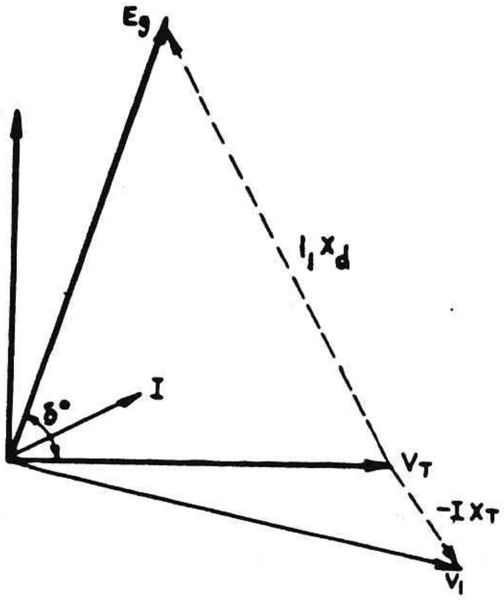
E.1 System Considered



E.2 Equivalent Circuit - (one phase only)



E.3 Vector Diagram



E.4 Calculation of V_1 In Terms Of V_S

With rated L.V. volts, V_L, and the nominal turns ratio N,

$$V_L V_R N = V_H V_N \qquad \text{(in volts)}$$

In general

$$V_1 V_R N_n = V_S V_N \qquad \text{(in volts)}$$

$$\therefore \quad V_1 = \frac{V_S V_N}{N_n V_R}$$

Substituting for V_R

$$V_1 = \frac{V_S V_N N V_L}{N_n V_H V_N}$$

But $\quad \frac{N_n}{N} = n$, p.u. turns ratio

$$\therefore \quad V_1 = \frac{V_S V_L}{n V_H} \qquad \text{Equation E1}$$

E.5 Calculation of Q_L, At The L.V. Side Of Generator Transformer

Considering the modulus of V_1

$$V_1^2 = \left[V_T - \left(\frac{Q_L X_T}{V_T}\right)\right]^2 + \left(\frac{P_L X_T}{V_T}\right)^2$$

$$\therefore \quad V_T - \left(\frac{Q_L X_T}{V_T}\right) = \pm \sqrt{V_1^2 - \left(\frac{P_L X_T}{V_T}\right)^2}$$

$$\therefore \quad Q_L = \frac{V_T^2}{X_T} \pm \sqrt{\left(\frac{V_1 V_T}{X_T}\right)^2 - P_L^2}$$

From Equation E1

$$V_1 = \frac{V_S V_L}{nV_H}$$

Substituting for V_1

$$Q_L = \frac{V_T^2}{X_T} \pm \sqrt{\left(\frac{V_S V_L V_T}{nV_H X_T}\right)^2 - P_L^2} \qquad \text{- Equation E2}$$

The largest value of Q_L should be ignored

E.6 Calculation of Q_M, At The Generator Terminals

$$Q_M = Q_L + Q_u$$

Substituting for Q_L from E.2.

$$Q_M = Q_u + \frac{V_T^2}{X_T} \pm \sqrt{\left(\frac{V_S V_L V_T}{nV_H X_T}\right)^2 - P_L^2} \qquad \text{- Equation E3}$$

The largest value of Q_M should be ignored.

E.7 Calculation of Q_H, On The H.V. Side Of The Generator Transformer

$$Q_H = Q_L - Q_T$$

MVAr Loss in generator transformer, $Q_T = S_L^2 \frac{X_T}{V_T^2}$

$$= \frac{X_T}{V_T^2}\left(P_L^2 + Q_L^2\right)$$

$$Q_H = Q_L - \frac{X_T}{V_T^2}\left(P_L^2 + Q_L^2\right) \qquad \text{- Equation E4}$$

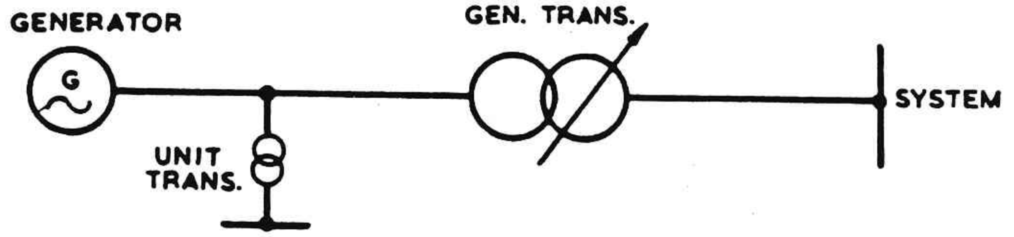
NOTE: Q_L is found from Equation E2.

APPENDIX F

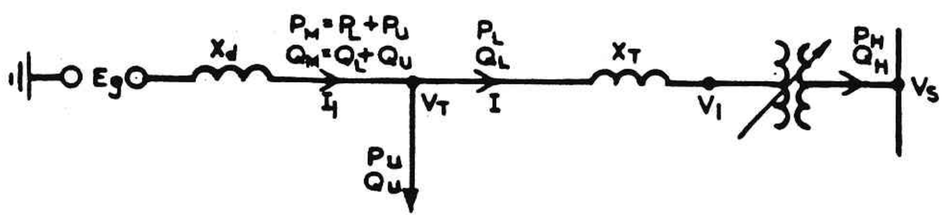
General Equations for a Generator Having a Transformer with Off-load Taps

Equations to be used in the plotting of performance charts for generators connected through transformers having off-load taps are derived in this Appendix. The general case of a generator with a unit transformer is considered. The terminal voltage of the generator varies.

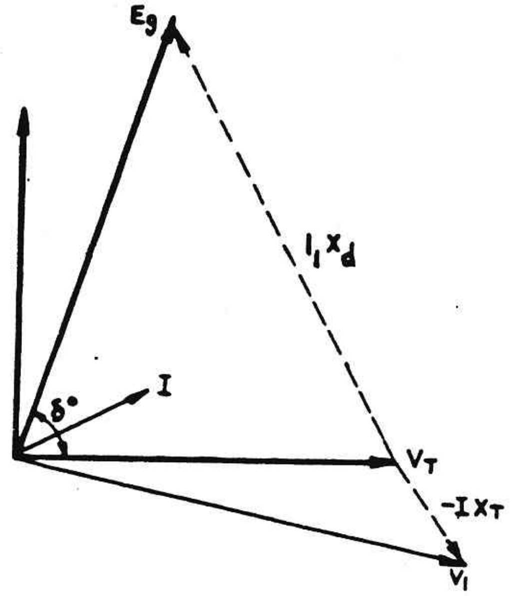
F.1 System Considered



F.2 Equivalent Circuit - (one phase only)



F.3 Vector Diagram



F.4 Calculation of V_T

Considering the modulus of V_1

$$V_1^2 = \left[V_T - \frac{Q_L X_T}{V_T}\right]^2 + \left(\frac{P_L X_T}{V_T}\right)^2$$

$$\therefore \quad V_1^2 \cdot V_T^2 = \left[V_T^2 - Q_L X_T\right]^2 + \left(P_L X_T\right)^2$$

$$\therefore \quad V_T^4 - V_T^2\left[2Q_L X_T + V_1^2\right] + X_T^2\left(Q_L^2 + P_L^2\right) = 0$$

\- Equation F1

Solving F1 for V_T^2

$$V_T^2 = \frac{\left(2Q_L X_T + V_1^2\right) \pm \sqrt{\left(2Q_L X_T + V_1^2\right)^2 - 4X_T^2\left(P_L^2 + Q_L^2\right)}}{2}$$

$$\therefore \quad V_T = \pm\sqrt{\frac{\left(2Q_L X_T + V_1^2\right) \pm \sqrt{\left(2Q_L X_T + V_1^2\right)^2 - 4X_T^2\left(P_L^2 + Q_L^2\right)}}{2}}$$

\- Equation F2

From Equation E1 in Appendix E, $V_1 = \frac{V_S V_L}{n V_H}$

Substituting for V_1 in equation F2

$$V_T = \pm\sqrt{\frac{\left[2Q_L X_T + \left(\frac{V_S V_L}{nV_H}\right)^2\right] \pm \sqrt{\left[2Q_L X_T + \left(\frac{V_S V_L}{nV_H}\right)^2\right]^2 - 4X_T^2\left(P_L^2 + Q_L^2\right)}}{2}}$$

$$\therefore \quad V_T = \pm\sqrt{Q_L X_T + \tfrac{1}{2}\left(\frac{V_S V_L}{nV_H}\right)^2 \pm \sqrt{\tfrac{1}{4}\left(\frac{V_S V_L}{nV_H}\right)^4 + Q_L X_T\left(\frac{V_S V_L}{nV_H}\right)^2 - \left(P_L X_T\right)^2}}$$

\- Equation F3

F.5 Calculation of Q_L for the case when $\delta = 90^\circ$

Ignoring the voltage drop in the generator due to the unit transformer loading, which is considered negligible.

$$V_T = \frac{-Q_L X_d}{V_T}$$

$$\therefore \quad V_T^2 = -Q_L X_d \qquad \text{- Equation F4}$$

Substituting for V_T^2 in Equation F3, and squaring

$$-Q_L X_d = Q_L X_T + \frac{1}{2}\left(\frac{V_S V_L}{nV_H}\right)^2 \pm \sqrt{\frac{1}{4}\left(\frac{V_S V_L}{nV_H}\right)^4 + Q_L X_T\left(\frac{V_S V_L}{nV_H}\right)^2 - \left(P_L X_T\right)^2}$$

$$-\left[Q_L\left(X_d + X_T\right) + \frac{1}{2}\left(\frac{V_S V_L}{nV_H}\right)^2\right] = \pm \sqrt{\frac{1}{4}\left(\frac{V_S V_L}{nV_H}\right)^4 + Q_L X_T\left(\frac{V_S V_L}{nV_H}\right)^2 - \left(P_L X_T\right)^2}$$

Squaring both sides

$$Q_L^2\left(X_d + X_T\right)^2 + Q_L\left(X_d + X_T\right)\left(\frac{V_S V_L}{nV_H}\right)^2 + \frac{1}{4}\left(\frac{V_S V_L}{nV_H}\right)^4$$

$$= \frac{1}{4}\left(\frac{V_S V_L}{nV_H}\right)^4 + Q_L X_T\left(\frac{V_S V_L}{nV_H}\right)^2 - \left(P_L X_T\right)^2$$

$$\therefore \quad Q_L^2\left(X_d + X_T\right)^2 + Q_L X_d\left(\frac{V_S V_L}{nV_H}\right)^2 + \left(P_L X_T\right)^2 = 0$$

Solving

$$Q_L = \frac{-X_d\left(\frac{V_S V_L}{nV_H}\right)^2 \pm \sqrt{X_d^2\left(\frac{V_S V_L}{nV_H}\right)^4 - 4\left(X_d + X_T\right)^2\left(P_L X_T\right)^2}}{2\left(X_d + X_T\right)^2}$$

$$\therefore \quad Q_L = \frac{X_d}{2\left(X_d + X_T\right)^2}\left(\frac{V_S V_L}{nV_H}\right)^2\left\{-1 \pm \sqrt{1 - \left[\frac{2P_L X_T}{X_d}\left(\frac{nV_H}{V_S V_L}\right)^2\left(X_d + X_T\right)\right]^2}\right\}$$

$$\text{- Equation F5}$$

F.6 Calculation of Q_M for the case when $\delta = 90^\circ$

$$Q_M = Q_L + Q_u \qquad \text{- Equation F6}$$

Q_L is obtained from Equation F5

F.7 Calculation of V_T for the case when $\delta = 90^\circ$

From Equation F4

$$V_T^2 = -Q_L X_d$$

Substituting for Q_L in Equation F5

$$V_T^2 = \frac{X_d^2}{2\left(X_d + X_T\right)^2}\left(\frac{V_S V_L}{nV_H}\right)^2\left\{1 \pm \sqrt{1 - \left[\frac{2P_L X_T}{X_d}\left(\frac{nV_H}{V_S V_L}\right)^2\left(X_d + X_T\right)\right]^2}\right\}$$

$$\therefore V_T = \frac{X_d}{\sqrt{2}\left(X_d + X_T\right)}\left(\frac{V_S V_L}{nV_H}\right)\sqrt{1 \pm \sqrt{1 - \left[\frac{2P_L X_T}{X_d}\left(\frac{nV_H}{V_S V_L}\right)^2\left(X_d + X_T\right)\right]^2}}$$

- Equation F7

F.8 Calculation of Q_H, on the H.V. Side of the Generator Transformer

In general, $Q_H = Q_L - Q_T$,

Q_T being the generator transformer MVAr loss for S_L load on the transformer L.V. side

$$Q_T = S_L^2\left(\frac{X_T}{V_T^2}\right)$$

$$\therefore Q_T = \frac{X_T}{V_T^2}\left[P_L^2 + Q_L^2\right] \qquad \text{- Equation F8}$$

NOTE: V_T is not constant and must be calculated from Equation F3 knowing Q_L.

APPENDIX G

Comparison of the Methods of this Document with those of Computer Program CHRT

South Eastern Region have developed a computer program (CHRT) for use in conjunction with this Planning Memorandum. The program calculates the performance limits for a generator using the same data and generally the same theory as this Memorandum; differences are mentioned in Clause G.1 below.

The output of the program can be fed into a graphical plotter to obtain a performance chart. Figs. G.1-G.L show computer drawn charts for the worked examples of Appendices C and D. The charts are compared in Clause G.2 below with those constructed manually and shown in Appendices C and D.

G.1 Differences between 'CHRT' and PLM-ST6

G.1.1 Generation Connection Arrangements

In this document the method of plotting a chart for a directly-connected generator is included with that for a generator connected through a transformer with on-load taps although the types are discussed separately and the assumptions to be made for directly-connected sets are detailed.

In the computer program report these arrangements are treated separately.

G.1.2 Symbols and Units

Symbols have been produced independently and thus in many cases differ. However, comprehensive lists of symbols and units used are included in both documents.

The units used in this document are in p.u. values. The MW, MVAr and MVA are based on 100 MVA for ease of calculation.

In the computer program report the MVA base of individual items is used and thus the initial data will differ slightly.

G.1.3 Limit Lines

The equations of limit lines, for cases in which the generator terminal voltage (V_T) is constant used in this document are similar to those used in the computer program report.

For cases in which the terminal voltage varies, assumptions regarding constant V_T are made in the computer program methods for limit lines on which V_T varies to allow the construction of straight lines or circles as appropriate. In this document it is recommended that account should be taken of the variation of V_T to plot these lines if a simpler pessimistic line, which is suggested for all cases, suggests that the line will impose a limit on performance.

Lines corresponding to terminal voltage restrictions, under-excitation limiter settings and maximum excitation limits (when assumed to be equal to that excitation which gives rise to rated power output and p.f.) are not claculated in the computer program. These lines must be plotted manually.

G.2 Comments on the Computer-Drawn Charts

G.2.1 L.V. Chart for Drakelow 'B' No.5 Set

The chart is shown in Fig. G.1 and should be compared to Fig. C.1. It will be noted that use of full and dotted lines on the chart is not consistent.

The lines constructed and shown on Fig.G.1 are similar to those on Fig.C.1. The following lines, however, are not constructed in the computer program and would have to be added manually:-

(a) Under-excitation limiter setting

(b) Assumed Maximum excitation limit

(c) Lagging MVAr tap-limit

G.2.2 H.V. Chart for Drakelow 'B' No.5 Set

The charts shown on Figs. G.2 and C.2 are similar, but again the limits (a) (b) and (c) above would have to be plotted manually.

G.2.3 L.V. Chart for Blyth 'A' No.3 Set

Comparing Figs. G.3 and D.1, the effects of the assumption of Constant V_T when constructing the minimum excitation limit and the rated MVA limit at lagging p.f. can be seen. Otherwise the lines constructed are similar.

The following lines are not constructed in the computer program and would have to be added manually.

(a) Under-excitation limiter setting

(b) Terminal voltage restriction limits

(c) Assumed maximum excitation limit

G.2.4 H.V. Chart for Blyth 'A' No.3 Set

Figs. G.4 and D.2 do not look similar. The limits caused by (a), (b) and (c) in G.2.3 above are not calculated in the computer program and would have to be added manually.

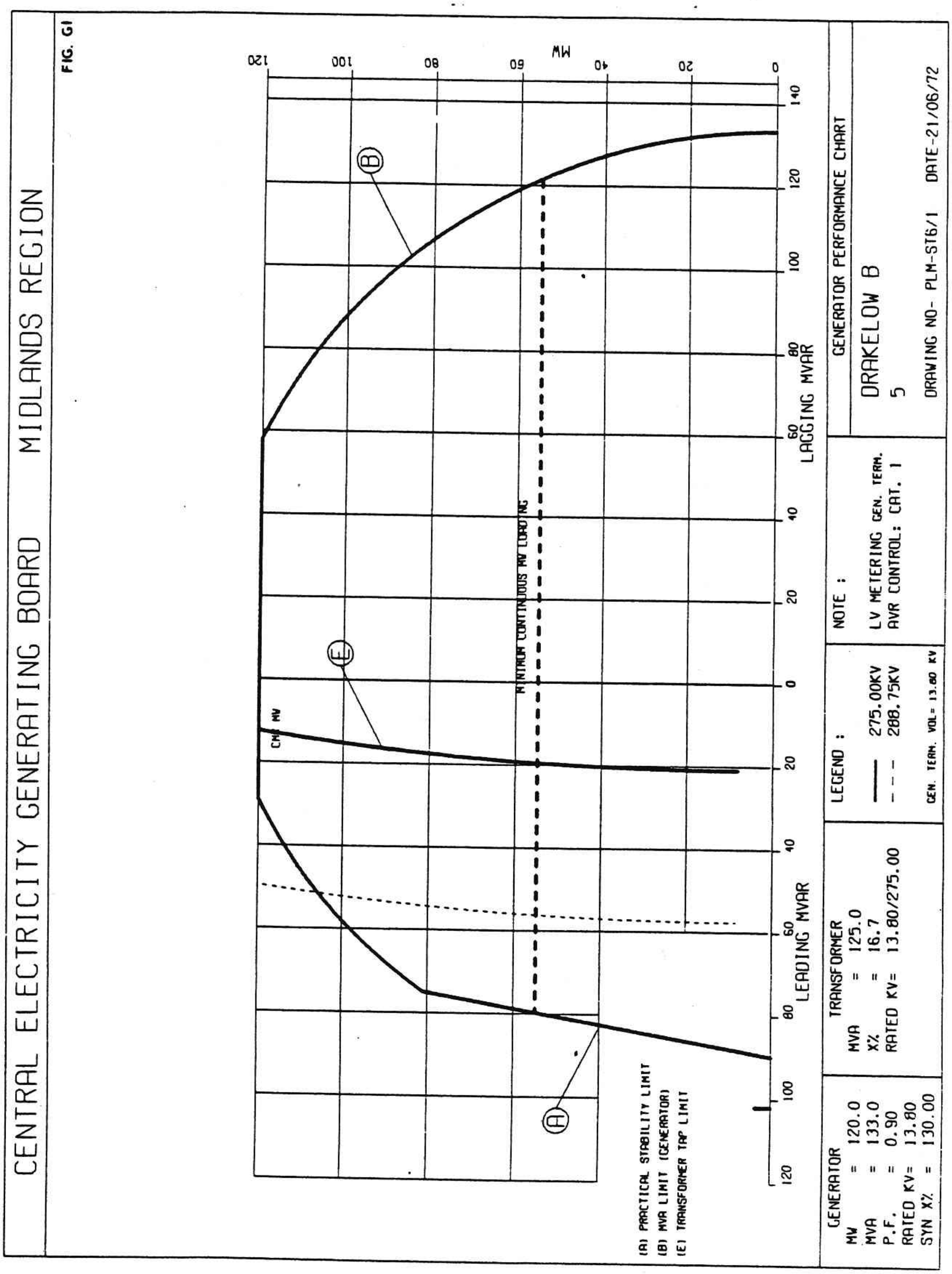

CENTRAL ELECTRICITY GENERATING BOARD MIDLANDS REGION
FIG. G1
MW
LAGGING MVAR
LEADING MVAR
MINIMUM CONTINUOUS MW LOADING
CMR MW
(A) PRACTICAL STABILITY LIMIT
(B) MVA LIMIT (GENERATOR)
(E) TRANSFORMER TAP LIMIT
GENERATOR
MW = 120.0
MVA = 133.0
P.F. = 0.90
RATED KV= 13.80
SYN X% = 130.00
TRANSFORMER
MVA = 125.0
X% = 16.7
RATED KV= 13.80/275.00
LEGEND :
275.00KV
288.75KV
GEN. TERM. VOL= 13.80 KV
NOTE :
LV METERING GEN. TERM.
AVR CONTROL: CAT. 1
GENERATOR PERFORMANCE CHART
DRAKELOW B
5
DRAWING NO- PLM-ST6/1 DATE-21/06/72

FIG. G1

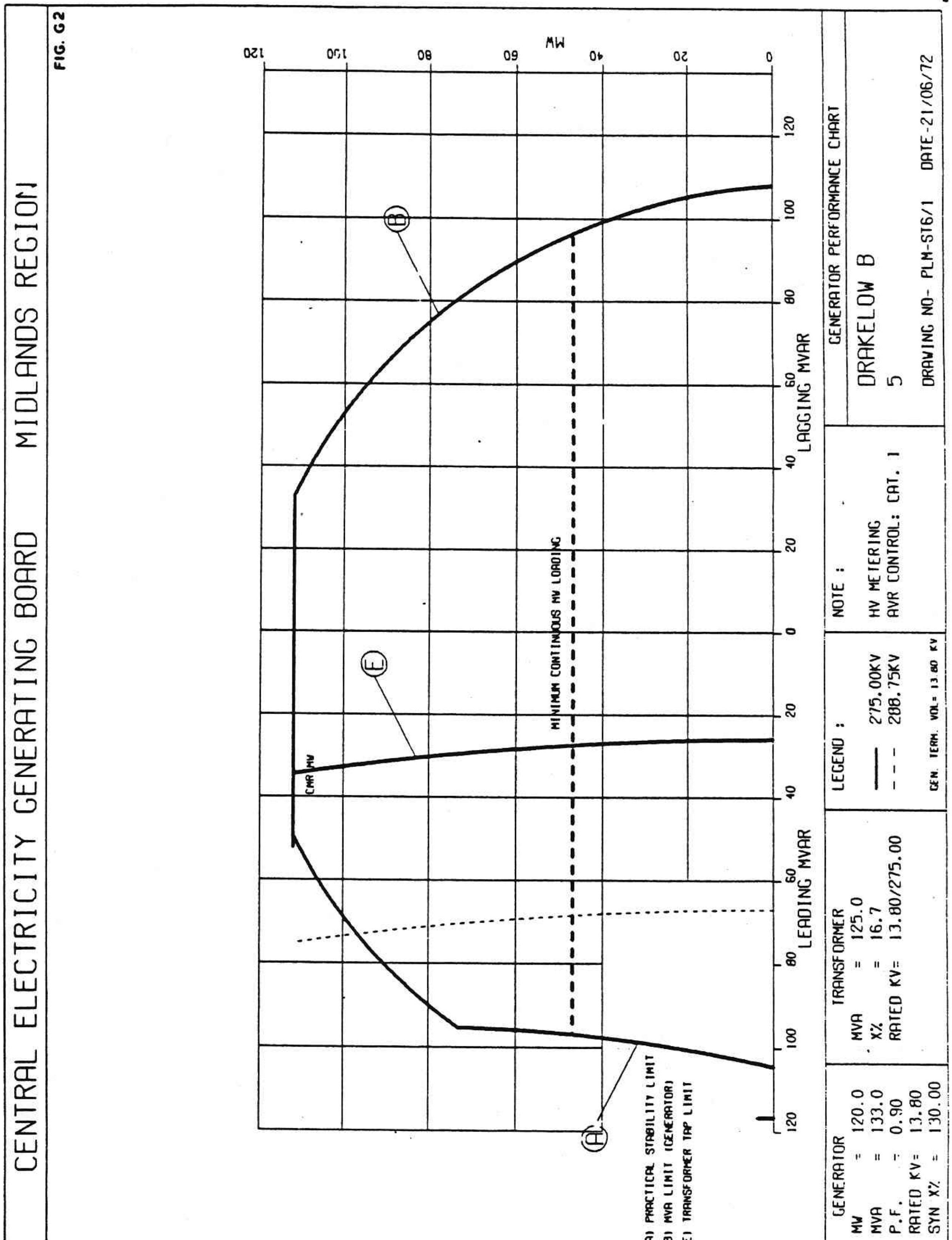

CENTRAL ELECTRICITY GENERATING BOARD MIDLANDS REGION
FIG. G2
MW
LAGGING MVAR
LEADING MVAR
MINIMUM CONTINUOUS MW LOADING
(A) PRACTICAL STABILITY LIMIT
(B) MVA LIMIT (GENERATOR)
(E) TRANSFORMER TAP LIMIT
GENERATOR
MW = 120.0
MVA = 133.0
P.F. = 0.90
RATED KV = 13.80
SYN X% = 130.00
TRANSFORMER
MVA = 125.0
X% = 16.7
RATED KV = 13.80/275.00
LEGEND :
275.00KV
208.75KV
GEN. TERM. VOL = 13.80 KV
NOTE :
HV METERING
AVR CONTROL: CAT. 1
GENERATOR PERFORMANCE CHART
DRAKELOW B
5
DRAWING NO- PLM-ST6/1
DATE-21/06/72

FIG. G2

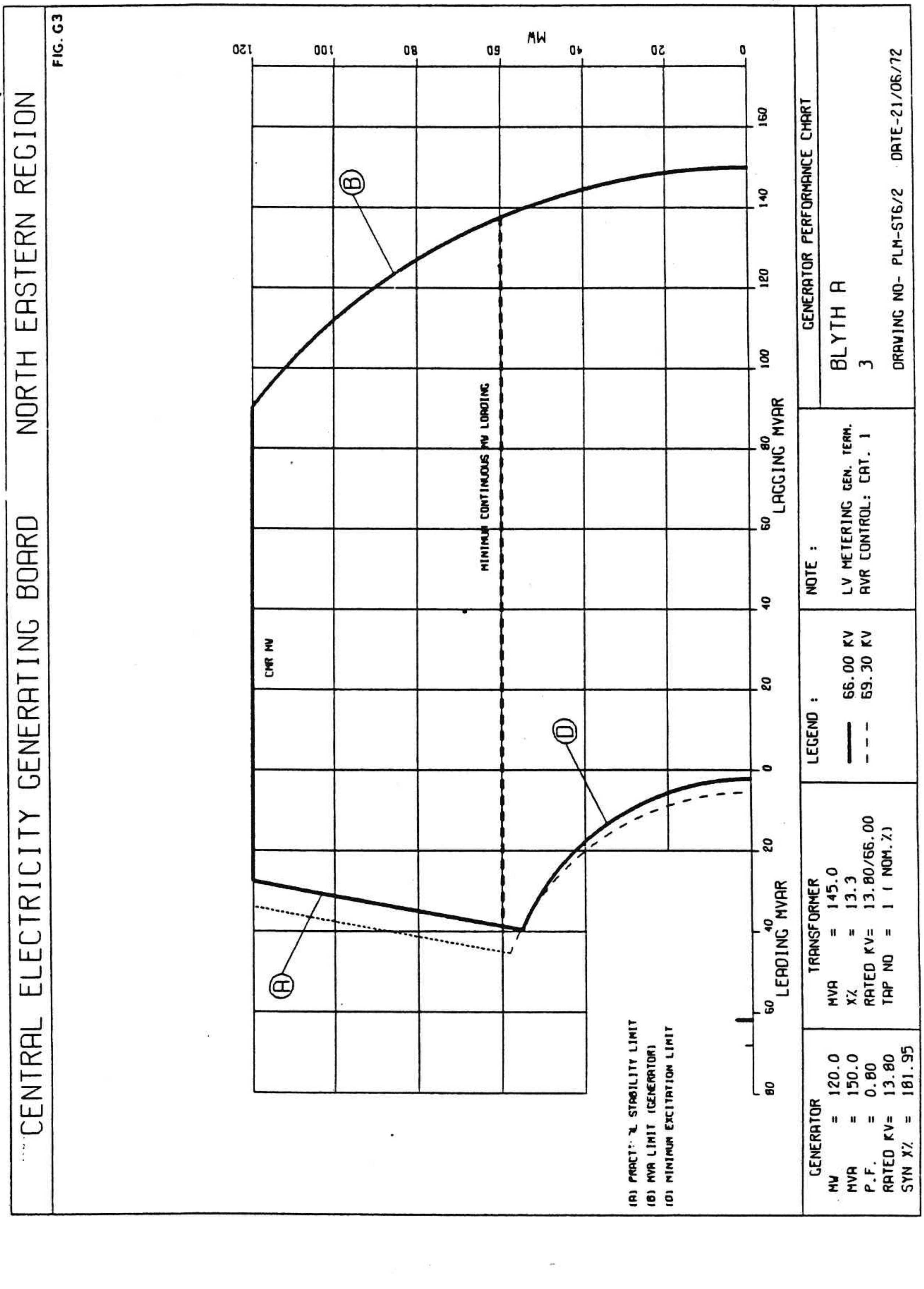

CENTRAL ELECTRICITY GENERATING BOARD NORTH EASTERN REGION
FIG. G3
MW
LAGGING MVAR
LEADING MVAR
MINIMUM CONTINUOUS MW LOADING
CMR MW
(A) PRACTICAL STABILITY LIMIT
(B) MVA LIMIT (GENERATOR)
(D) MINIMUM EXCITATION LIMIT
GENERATOR
MW = 120.0
MVA = 150.0
P.F. = 0.80
RATED KV= 13.80
SYN X% = 181.95
TRANSFORMER
MVA = 145.0
X% = 13.3
RATED KV= 13.80/66.00
TAP NO = 1 (NOM.%)
LEGEND :
66.00 KV
69.30 KV
NOTE :
LV METERING GEN. TERM.
AVR CONTROL: CAT. 1
GENERATOR PERFORMANCE CHART
BLYTH A
3
DRAWING NO- PLM-ST6/2 DATE-21/06/72

FIG. G3

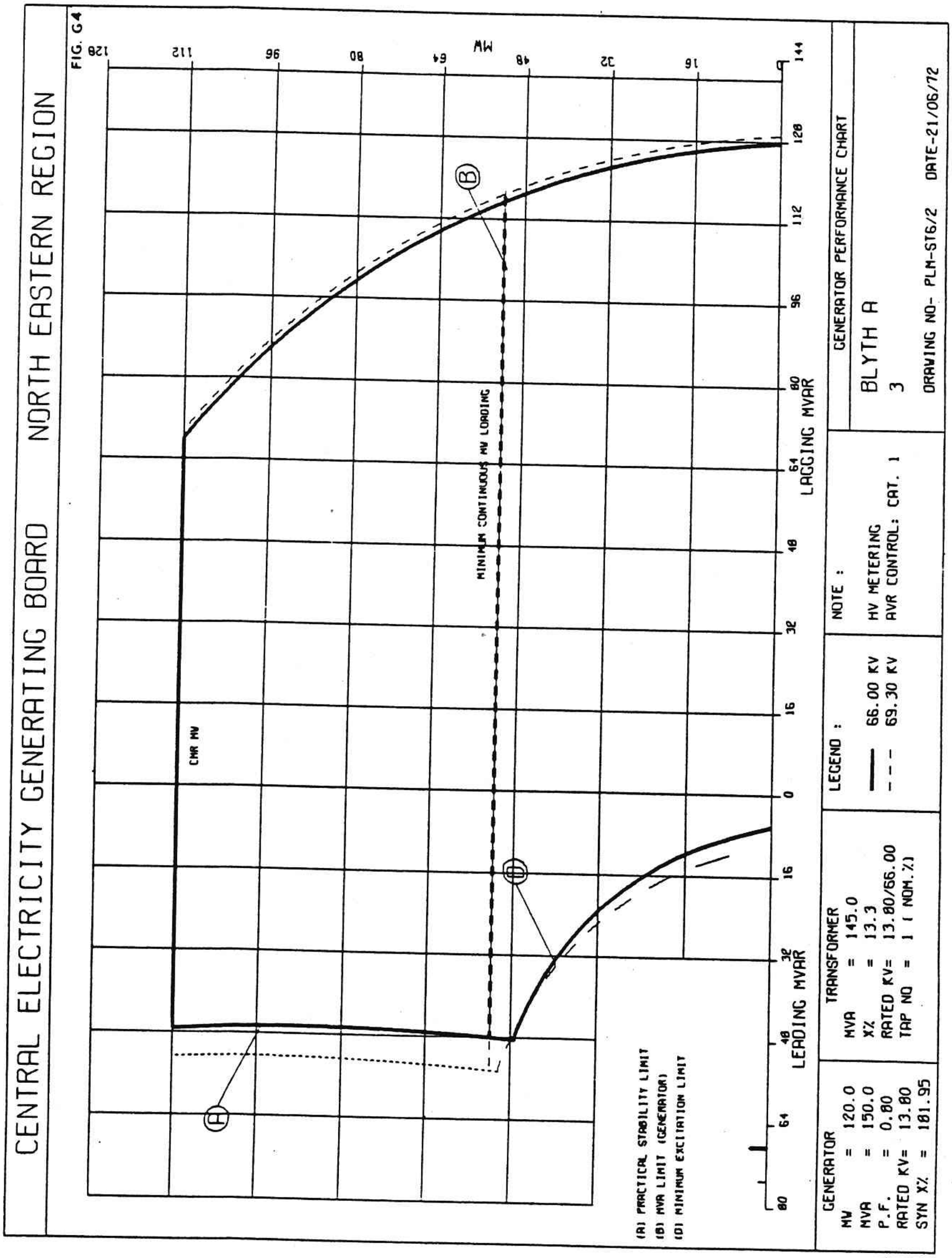

CENTRAL ELECTRICITY GENERATING BOARD NORTH EASTERN REGION
FIG. G4
MW
LAGGING MVAR
LEADING MVAR
MINIMUM CONTINUOUS MW LOADING
CMR MW
(A) PRACTICAL STABILITY LIMIT
(B) MVA LIMIT (GENERATOR)
(D) MINIMUM EXCITATION LIMIT
GENERATOR
MW = 120.0
MVA = 150.0
P.F. = 0.80
RATED KV= 13.80
SYN X% = 181.95
TRANSFORMER
MVA = 145.0
X% = 13.3
RATED KV= 13.80/66.00
TAP NO = 1 (NOM.%)
LEGEND :
66.00 KV
69.30 KV
NOTE :
HV METERING
AVR CONTROL: CAT. 1
GENERATOR PERFORMANCE CHART
BLYTH A
3
DRAWING NO- PLM-ST6/2 DATE-21/06/72

FIG. G4

CIRCULATION LIST FOR PLANNING MEMORANDUM PLM–ST–6

Regions

Director of Resource Planning (MR, NWR, SER) (10)
Director of Transmission (NWR, SWR) (10)
Director of Production (MR, SER, NER) (10)
Director of Generation (NWR, SWR) (10)
Director of Engineering (MR, SER, NER) (10)
System Operation Engineers (All Regions) (10)

GD & CD

Director of Plant Engineering (2)
Director of Station Design (2)
Turbo-generator Design Engineer (2)
Systems Engineer (2)
Electrical Machines Engineer (2)
Electrical Plant Engineer (2)

TD & CD

Director of Design (2)

Operations Department, HQ

Director of Operations (2)
System Operation Engineer (2)
National Control Manager (2)
System Co-ordination Engineer (2)

Planning Department, HQ

Director of Planning (1)
Generation and Transmission Development Engineer (2)
Generation Studies Engineer (2)
System Planning Engineer (2)
System Technical Engineer (25)

SSEB

Transmission Design Engineer (2)
System Operation Manager (2)

NSHEB

Chief Transmission and Distribution Engineer (2)
Chief System Operation Engineer (2)

Requests for changes in circulation should be addressed to the Branch Head responsible for initiating the Memorandum.