ON LINE MONITORING OF HIGHER RATED ALTERNATOR USING "AUTOMATED GENERATOR CAPABILITY CURVE ADMINISTER"

G. SANGEETHA[1], SHERINE[2]
[1]PG Scholar, BIHER, Chennai
[2]Associate Professor, BIHER, Chennai

ABSTRACT

On Line Monitoring of Higher Rated Alternator of ≥30MW capacity using "Automated Generator Capability Curve Administer" provides the correct operating regions of the Alternator. By giving the Generator ratings from the design data, the Administer draws the Capability curve for the given Generator by using MATLAB program. The operating point of the running Generator is also drawn in the Capability curve after giving the Voltage and Current inputs from Potential Transformer (PT) and Current Transformer (CT) respectively. The running Generator parameters are calculated from the Capability curve by using MATLAB program and display all the parameters of the running Generator including its Field Current and Load Angle which are not being measured in the conventional metering system used.

Keywords: Capability Curve, Alternator, Generator, Excitation.

1. INTRODUCTION:

To draw the Capability curve of any Synchronous Generator for which the name plate / manual input details are to be given and it will generate all the operating parameters after getting the present working point details from any two inputs.

The following inputs are to be given to "Automated Generator Capability Curve Administer" for drawing the Capability curve of a given Generator by using MATLAB program:

- Rated MVA
- Rated Terminal Voltage
- Rated Power Factor
- Short Circuit Ratio
- Rated Armature Current
- Rated Field Current
- Stability Margin

From the inputs, the Administer calculates the Rated MW, Maximum permissible zero power factor leading MVAR limit, Power factor Angle and Practical Load Angle Stability Margin in leading power factor zone. The Administer draws the Capability Curve for the given and calculated data using MATLAB program. By giving any two actual inputs of running Generator, the Administer plot the working point of the Generator and print all the following parameters of the Generator.

1. Real Power in MW
2. Reactive Power in MVAR
3. Operating Power factor
4. Stator (Armature) current in Amps.
5. Rotor (Field) current in Amps.
6. Generator terminal voltage
7. Phase angle (ø)
8. Load angle (δ)

The "Automated Generator Capability Curve Administer" will replace all the metering panels of Generator used for generation in Thermal, Hydel, Gas and Nuclear Power Plants.

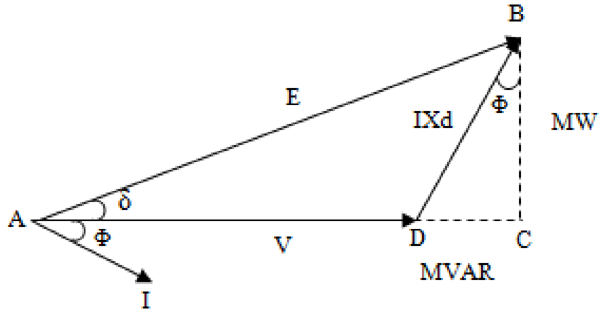
2. REVIEW ON GENERATOR CAPABILITY CURVE:

Normally the Generator capability curves are drawn manually. The power diagram shown in Fig.1 gives the Real power and Reactive power in terms of Actual Voltage Generated (E), System Voltage (V), Load Angle (δ) and Synchronous Reactance (X_d)

Case-I:

In Δ ABC, BC=E Sinδ
In Δ BCD, BC=IXd CosΦ
E Sinδ = IXd CosΦ   Multiply both sides by V/ Xd
EVSinδ/Xd = VICosΦ = REAL POWER
At δ=90°, We get the maximum power i.e. the theoretical stability line.

Fig.1: Power diagram



Case-II:

In Δ ABC, CD=AC – AD;
In Δ BCD, CD=IXd SinΦ
In Δ ABC, AC=E Cosδ & AD = V
IXd SinΦ = E Cosδ - V;
Multiply both sides by V/Xd, We get
(EV Cos δ/Xd) – (V^2/Xd) = VI Sin Φ = REACTIVE   POWER

3. METHOD AND IMPLEMENTATION:

The algorithm to draw the Generator Capability Curve in MATLAB software is given below:

3.1 Algorithm:

Step -1: Start the program.

Step-2:   Input the following information from the
Turbo-Generator Name plate/ Manual:

(i) Terminal Voltage in volts.
(ii) Rated MVA.
(iii) Rated Armature current in Amps.
(iv) Rated Field current in Amps.
(v) Short Circuit Ratio (SCR)
(vi) Load Angle Limiter Margin in %

Step-3: Calculate the following parameters using the input data:

(i) Rated MW = Rated MVA x Rated Power factor
(ii) Maximum permissible zero power factor leading MVAR = Rated MVA x SCR
(iii) Power angle in degrees, $\varphi = \cos^{-1}$ (PF)
(iv) Power rating margin in pu. = Power factor x (Load angle limiter margin in % / 100)
(v) Generate a plotting points for practical stability limit line:

pu. MW	0	0.1	0.2	…	0.9	1.0
pu. MW + Power rating margin in pu.						

Step-4: **Draw the capability curve**

(i) Take scale 1cm = 0.1 pu
(ii) Plot X-axis, centre point is marked as O.
From O to left: Mark pu MVAR leading. Also mark 0 – 1 pu in steps of 0.1 pu. At 1.0 pu, mark A.
From O to right: Mark pu MVAR lagging. Also mark 0-1pu in steps of 0.1 pu. At 1.0 pu, Mark C.
At O, draw a perpendicular line upwards and mark pu MW. Also mark 0-1 pu in steps of 0.1 pu and at 1.0 pu, mark B.
(iii) Draw half circle with centre point O and radius OA. The half circle cuts the pu MW line at B and pu MVAR lagging line at C.
(iv) Draw parallel line to X-axis above B in the pu MW line and mark the point which cuts the pu MW line as unity power factor. Mark *"Lagging pf, VAR export"* towards lagging MVAR side and mark *"Leading pf, VAR import"* towards leading MVAR side.
(v) Fix the pf angle φ with centre O from pu MW line towards lag or lead side according to input [Step 2: (iii)] and draw a line from O to half circle which cut the half circle at D. At D, the pf is rated one. The line OD is the *"Total Armature or Stator Current"* [1.0 pu = the rated armature current in amps i.e. the input given Step 2: (iii)]. Mark the angle φ in between the lines OB and OD.
(vi) Draw a parallel line to X-axis from point D which cuts the half circle. This line is *"Turbine limit line".*
(vii) In the line OA, mark the SCR value and this point is E. OE is the *"Maximum permissible MVAR in zero pf leading"* and this value is Rated MVA x SCR. [Step 3: (ii)]
(viii) Draw a perpendicular line to X-axis at E and it is called the "Theoretical Stability Limit line". Draw a dotted line from pu MW line to theoretical stability limit line parallel to X-axis from 0 to 1.0pu in steps of 0.1pu.

(ix) Draw a line between E and D which is "Total field or Rotor current". At D, we get Rated Field Current [Step 2: (v)].

(x) Draw an arc with E as centre and ED as radius which connects the point D and the arc cut the X-axis is marked as H. This arc is *"Rotor Current Limit Line".*

(xi) The half circle portion between CD is "*Stator Current Limit Line*".

(x) From the table generated [Step 3: (iv)], we can plot the Practical Stability Limit Line.
For 0pu MW: Take 0pu MW + power rating margin in pu as radius and with centre at E, make an arc from theoretical stability line to 0 pu MW line in X-axis which cuts the X-axis at F.
For 0.1pu MW: Take 0.1pu MW + the power rating margin in pu as radius and with centre at E, make an arc from theoretical stability line to 0.1pu MW dotted line parallel to X-axis (mark a dot).
Repeat the same upto 1.0pu MW.
Connect all the dots by drawing a line which is called "Practical Stability Limit Line" with the given % [Step 2: (vii)] of margin.
The practical stability limit line cuts the turbine limit line and this point is marked as G. The angle from X-axis to practical stability limit line with F as centre is called "Load Angle" in degrees.

(xi) Generate the following text outside the diagram:

OE is the "No load field current".
OD is the "Field current required for armature reaction".
FGDH is the "Capability area of given generator"

(xi) Divide 10 equal parts of line ED from ED line and practical stability limit line to X-axis and mark 0.1 to 1.0 pu in steps of 0.1pu.

Step 5: Plotting of working point:

Get any two of the output parameters shown below from the running generator:

MW		
MVAR		
Power factor (pf)		Lag
		Lead
	Unity	
Armature Current in Amps.		
Field Current in Amps.		
Generator Voltage in Volts.		

(i) If the input is MW & MVAR,
pu. MW = MW / MVA
pu. MVAR = MVAR / MVA
Mark the working point by plotting the pu. MW & pu. MVAR.

(ii) If the input is MW & Power factor,

pu. MW = MW / MVA
$\varphi = \cos^{-1}(pf)$
Mark the working point by plotting the pu. MW & Power factor angle φ from pu MW line with O as centre.
Plot the other inputs and find the working point.

(iii) The other Generator output parameters are calculated as follows:

- Armature Current = Armature Current pu value X Rated Armature Current [Step2: (iv)]
- Field current = Field Current pu value X Rated field current [Step2:(v)]
- Power factor = Cos φ (φ value measured from the diagram)
- Load angle δ = δ value measured from X axis to Practical stability limit line with F as centre.

- Generator Terminal Voltage = $[(\sqrt{MW^2+MVAR^2})X10^6] / [\sqrt{3}$ X Armature Current]

Step 6: Print all the output parameters of Generator:

(i) MW
(ii) MVAR
(iii) Armature Current in Amps.
(iv) Field Current in Amps.
(v) Power factor, Cos φ
(vi) Load angle (δ)
(vii) Generator terminal voltage in Volts

3.2 IMPLEMENTATION:

3.2.1 Collect the Information from T.G. Name plate / Manual:

1. Rated Voltage	:	21,000 V
2. Rated MVA	:	705.9
3. Rated p.f. (cos Φ)	:	0.85 Lagging
4. Rated Armature Current	:	19407 A
5. Rated Field Current	:	5192 A
6. Short Circuit Ratio	:	0.57
7. Stability Margin in %	:	10 – 12%

II) CALCULATED VALUES:

1. MW = MVA X p.f. = 705.9 X 0.85 = 600.015 MW
2. MVAR = MVA X SCR = 705.9 X 0.57 = 402.363 MVAR (Max. permissible zero p.f. leading MVAR)

3. $\Phi = \cos^{-1}(0.85) = 31.79°$

4. To ensure operational safety, there should be a margin of at least 12.5 % (given by the manufacturer) of the power rating of the generator between the working point & the theoretical stability (load angle ‘δ’) limit line. The operational limit of a generator rated at 0.85 p.f. lagging can be tabulated below:

pu. MW	0	0.1	0.2	…	0.9	1.0
pu. MW+ Power rating margin in pu.	0.102	0.202	0.302	…	1.02	1.102

The capability curves drawn for the generator using the information collected from the name plate / manual and calculated values are shown in Fig.2 :

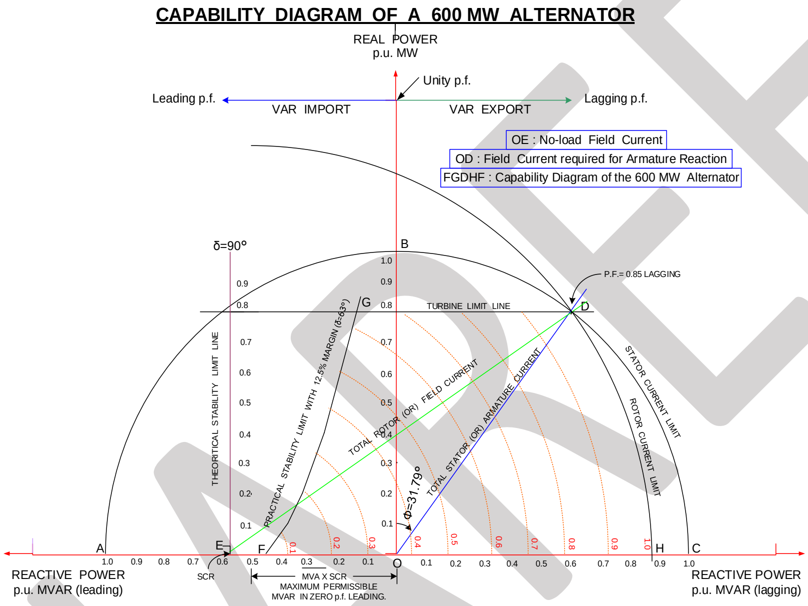
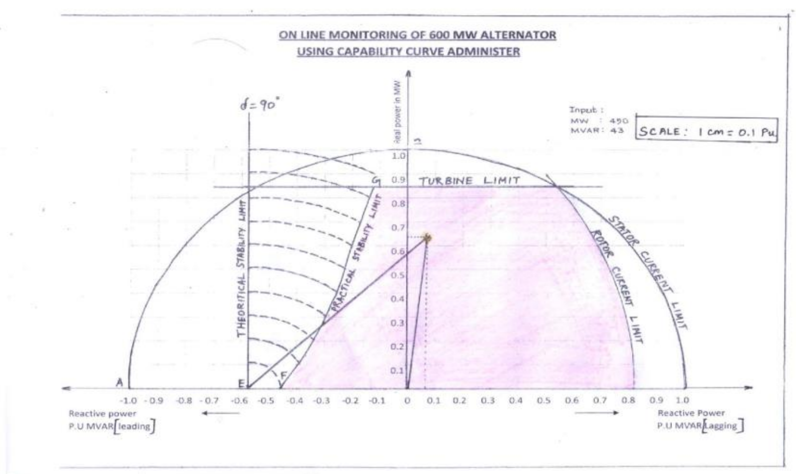


FIG. 2 capability curves drawn for the generator

4. RESULT:

By plotting any two inputs of running generator in the Capability curve i.e. MW and MVAR, the other parameters are calculated from the curve as shown below:



- Actual MW= 450 (i.e. 450/705.9 = 0.637 p.u.)
- Actual MVAR = 43 (i.e. 43/705.9 = 0.061 p.u.)
- Stator Current = 0.64 p.u. X 19407 A=12420 A
- Rotor Current = 8.95/14 p.u.X 5192 A =3338A
- p.f. = cos(5.5°) = 0.995 lag
- Load Angle 'δ' = 45°
- Voltage = $(MVA \times 10^6) / (\sqrt{3} \times Is.) = (\sqrt{(MW^2+MVAR^2)} \times 10^6) / (\sqrt{3} \times Is.)$

  $= (\sqrt{(450^2+43^2)} \times 10^6) / (\sqrt{3} \times 12420)$

  = 21.01 KV

The calculated values from the Capability curve shown above are compared with the actual values taken from the North Chennai Thermal Power Station Unit-2:

- ✓ MW = 450
- ✓ MVAR =43
- ✓ Armature Current = 12412 A
- ✓ Field Current = -- (No measurement)
- ✓ p.f.= 0.994 lag
- ✓ δ = -- (No measurement)
- ✓ V = 21.01 KV

The actual values are very nearer to the results obtained from the Capability curve. The Capability curves are used for the following:

4.1. USED FOR LIMITER SETTINGS IN EXCITATION:

A. *Rotor current limit*
   Class of insulation (to take care of rotor insulation)
B. *Stator current limit*
   Class of insulation for stator.

C. *MW load limit*
   Turbine limit (steam power generation capability)
   Turbine is designed for MW load only.
D. *Minimum load angle limit*
   Leading p.f. operation
   Stability limit of generation
E. *Stator end heating limit*
   Stressing stator winding & heating of stator
   10 to 20 MVAR (leading p.f.) is safe
   Rotor is relieved from stress
   Stator end winding heated due to capacitive effect
   Remove capacitor banks in load centers

4.2. USEFULNESS OF CAPABILITY DIAGRAM FOR EXCITATION CONTROL:

- The information given by the capability diagram regarding full load rotor current (excitation), maximum rotor angle during steady state leading p.f. zone operation (<75°) etc., are essential for proper setting of the various limiters in the excitation control system.
- Capability diagram give the basic information regarding the limiting zones of the operation so that limiters can be set / commissioned suitably for safe operation of the units.

5. CONCLUSION:

The Capability Curve drawn using MATLAB program gives the output parameters of running Generator which replaces the existing metering panels of Generator there by implementing the cost effectiveness. The "Stator Current Limiter", "Rotor Current Limiter" and "Load Angle Limiter" settings are incorporated in Static Excitation System & Brushless Excitation System using the Capability Curve.

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