Regulation of Alternators

Phasor diagram of an alternator at lagging power factor is as follows.

Regulation is found by the following expression

\[ \% \text{regn} = \frac{E_0 - V}{V} \times 100 \]

where \( V \) is the terminal voltage and \( E_0 \) is the induced voltage. \( E_0 \) is estimated by one of the following methods.

**EMF method**
(Synchronous impedance method)

Tests:
Conduct tests to find
- OCC (upto 125% of rated voltage)
- SCC (for rated current)
- Armature resistance (per phase)

\[ V = \text{rated phase voltage} \]
\[ I_{sc} = \text{short circuit current corresponding to the field current producing the rated voltage} \]

Synchronous impedance per phase,

\[ Z_s = \frac{V}{I_{sc}} \]

\[ X_s = \sqrt{Z_s^2 - R_a^2} \]

For any load current \( I \) and phase angle \( \Phi \), find \( E_0 \) as the vector sum of \( V, IR_a \) and \( IX_s \)

For lagging power factor

\[ E_0 = \sqrt{(V \cos \Phi + IR_a)^2 + (V \sin \Phi + IX_s)^2} \]

For unity power factor

\[ E_0 = \sqrt{(V + IR_a)^2 + (IX_s)^2} \]

For leading power factor

\[ E_0 = \sqrt{(V \cos \Phi + IR_a)^2 + (V \sin \Phi - IX_s)^2} \]
**MMF method**  
(Ampere turns method)

Tests:
Conduct tests to find
  OCC (upto 125% of rated voltage)  
  SCC (for rated current)

Steps:
1. By suitable tests plot OCC and SCC
2. From the OCC find the field current $I_{f1}$ to produce rated voltage, $V$.
3. From SCC find the magnitude of field current $I_{f2}$ to produce the required armature current.
4. Draw $I_{f2}$ at angle $(90+\Phi)$ from $I_{f1}$, where $\Phi$ is the phase angle of current from voltage. If current is leading, take the angle of $I_{f2}$ as $(90-\Phi)$.
5. Find the resultant field current, $I_f$ and mark its magnitude on the field current axis.
6. From OCC find the voltage corresponding to $I_f$, which will be $E_0$.

**ZPF method**  
(Potier method)

Tests:
Conduct tests to find
  OCC (upto 125% of rated voltage)  
  SCC (for rated current)  
  ZPF (for rated current and rated voltage)  
  Armature Resistance (if required)

Steps:
1. By suitable tests plot OCC and SCC
2. Draw tangent to OCC (air gap line)
3. Conduct ZPF test at full load for rated voltage and fix the point B.
4. Draw the line BH with length equal to field current required to produce full load current at short circuit.
5. Draw HD parallel to the air gap line so as to touch the OCC.
6. Draw DE parallel to voltage axis. Now, DE represents voltage drop $IX_L$ and BE represents the field current required to overcome the effect of armature reaction.
   **Triangle BDE is called Potier triangle and $X_L$ is the Potier reactance**
7. Find $E$ from $V$, $IX_L$ and $\Phi$. Consider $R_a$ also if required. The expression to use is
   $$E = \sqrt{(V \cos \Phi + IR_a)^2 + (V \sin \Phi + IX_L)^2}$$
8. Find field current corresponding to $E$.
9. Draw FG with magnitude equal to BE at angle $(90+\Psi)$ from field current axis, where $\Psi$ is the phase angle of current from voltage vector $E$ (internal phase angle).
10. The resultant field current is given by OG. Mark this length on field current axis.
11. From OCC find the corresponding $E_0$. 
ASA method

Tests:
Conduct tests to find
  OCC (upto 125% of rated voltage)
  SCC (for rated current)
  ZPF (for rated current and rated voltage)
  Armature Resistance (if required)

Steps:
1. Follow steps 1 to 7 as in ZPF method.
2. Find \( I_{f1} \) corresponding to terminal voltage \( V \) using air gap line (OF1 in figure).
3. xDraw \( I_{f2} \) with length equal to field current required to circulate rated current during short circuit condition at an angle (90+\( \Phi \)) from \( I_{f1} \). The resultant of \( I_{f1} \) and \( I_{f2} \) gives \( I_{f} \) (OF2 in figure).
4. Extend OF2 upto F so that F2F accounts for the additional field current accounting for the effect of saturation. F2F is found for voltage E as shown.
5. Project total field current OF to the field current axis and find corresponding voltage \( E_0 \) using OCC.

Slip Test
(for salient pole machines only)

Tests:
Conduct tests to find
  \( X_d \) and \( X_q \)
  Armature Resistance (if required)

1. Energise the alternator with field unexcited and driven close to synchronous speed by a prime mover.
2. Measure the line voltage and line current of the alternator.
3. Find \( X_d \) and \( X_q \) by the following expressions
   \[
   X_d = \frac{V_{\text{max}}}{\sqrt{3}I_{\text{min}}}  \quad X_q = \frac{V_{\text{min}}}{\sqrt{3}I_{\text{max}}}
   \]
4. Find \( I_d \) as follows
   \[
   \Psi = \tan^{-1} \frac{V\sin\Phi + 1X_q}{V\cos\Phi + 1R_a}  \quad I_d = I\sin\Psi
   \]
5. Then expression for \( E_0 \) is
   \[
   E_0 = \left[ (V\cos\Phi + IR_a)^2 + (V\sin\Phi + IX_q)^2 \right]^{1/2}
   + I_d (X_d - X_q)
   \]