Investigation of a Wind Power Generator

Part 2

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CONTENTS

Appendix

1 INTRODUCTION

The following work is Part 2 of a study regarding a technical investigation of the wind power generator at Hönö (Hönö 3, generator Morley 27/48/1). This work deals with the question of the differences between the two principles to make reactive power compensation; parallel compensation and series compensation.

Part 1 of this study ([1]) deals with FEM-analysis applied on the generator and consequences based on this FEM-analysis

2 SERIES- AND PARALLELL COMPENSATION.

The electrical power from the single stator module could in an ordinary way be expressed according to:

(Equation 1) $S = P + jQ$, where

S: the complex apparent power, P: the active power, Q: the reactive power

The reactive power from the stator module is in the first place an effect of the stator coil inductance. It is of interest to reduce the reactive power consumption as much as possible. There are two different suitable main methods present; the parallel compensation (a capacitor parallel with the stator coil) and the series compensation (a capacitor in series with the stator coil). See below in Figure 1 and Figure 2. Referring to the symbols in the figures:

U(t): the induced voltage, R: the coil resistance, L: the coil inductance, C: a capacitor to reduce the reactive power and Load: represents the load in question

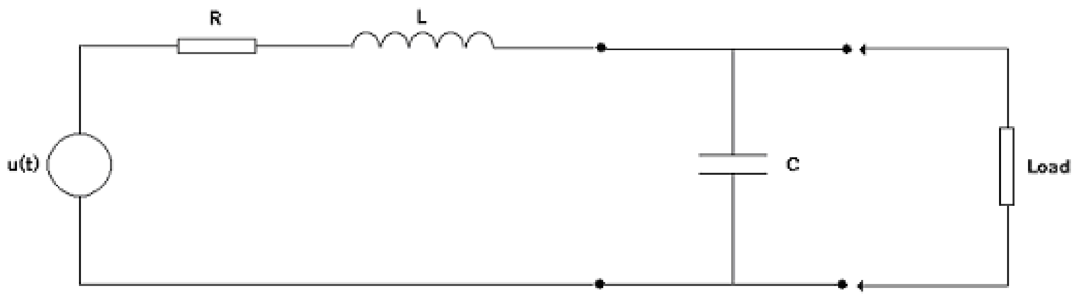

Figure 1 The principle for parallel compensation.

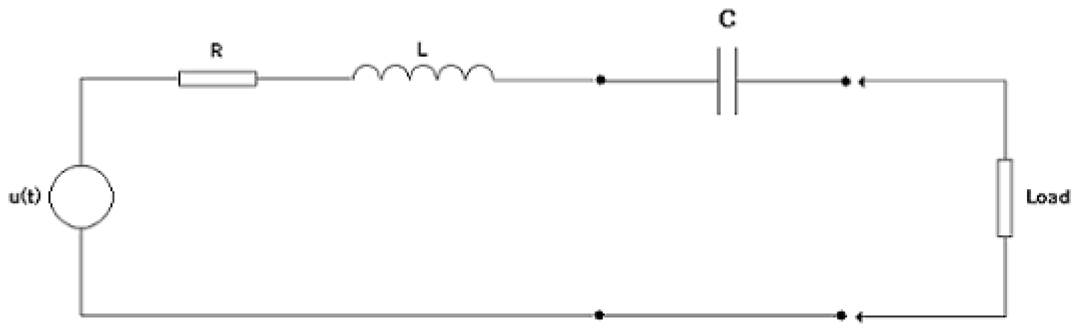

Figure 2 The principle for series compensation

The following is an analysis to find out some important differences between the two compensating methods.

The correlation between the electric angle speed, ω, and the rotating speed (rpm), V_{rot}, is:

(Equation 2) $$\omega = \frac{V_{rot} \cdot 2\pi \cdot P}{60}$$ where P = 24 is the number of pole pair.

3 PARALLEL COMPENSATION

The following is a circuit analysis regarding the equivalent circuit of a stator coil in combination with parallel compensation. The question that should has it’s answer is: “what conditions should be fulfilled to get maximum active power from the stator coils”.

Figure 3 gives the circuit principle for the parallel compensation.

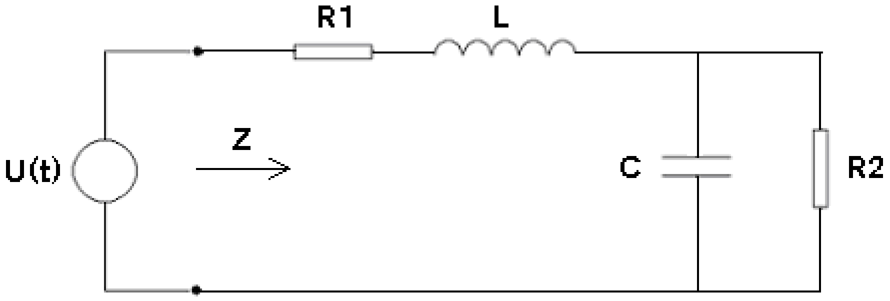

Figure 3 The principle of the parallel compensation.
U(t): induced voltage in the coil, R1: coil resistance, R2: load resistance (it is assumed a resistive load), L: coil inductance, C: capacitance for compensation

The impedance Z in the circuit is:

(Equation 3)
$$Z = R_1 + j\omega L + \frac{\frac{1}{j\omega C} \cdot R_2}{\frac{1}{j\omega C} + R_2}$$

For maximum compensation the phase angle of Z should be zero.

Developing of (Equation 3) gives:

$$Z = \frac{R_1 + R_2 - \omega^2 LCR_2 + j\omega(L + CR_1R_2)}{1 + j\omega CR_2} = \frac{|A| \cdot e^{j\varphi 1}}{[B] \cdot e^{j\varphi 2}} = [C] \cdot e^{j(\varphi 1 - \varphi 2)}$$

(Equation 4)
$$Z = [C] \cdot e^{j(\varphi 1 - \varphi 2)}$$

(Equation 5)
$$\varphi 1 = \arctan \frac{\omega(L + CR_1R_2)}{R_1 + R_2 - \omega^2 LCR_2}$$

(Equation 6) $\varphi 2 = \arctan\ \omega C R_2$

For maximum compensation Z is quite resistive and φ1 = φ2. That gives:

(Equation 7) $$\omega C R_2 = \frac{\omega(L + C R_1 R_2)}{R_1 + R_2 - \omega^2 L C R_2}$$

or:

(Equation 8) $$C^2 - C\frac{1}{\omega^2 L} + \frac{1}{\omega^2 {R_2}^2} = 0$$

This gives the following solution:

(Equation 9) $$C = \frac{1}{2\omega^2 L} \pm \sqrt{\left(\frac{1}{2\omega^2 L}\right)^2 - \frac{1}{\omega^2 {R_2}^2}}$$

As C has to be real (passive components are suggested) the following has to be satisfied:

(Equation 10) $$\left(\frac{1}{2\omega^2 L}\right)^2 \geq \frac{1}{\omega^2 {R_2}^2}$$

Looking for the maximum load for perfect compensation, than R_2 should be chosen as low as possible. That means:

(Equation 11) $$\left(\frac{1}{2\omega^2 L}\right)^2 = \frac{1}{\omega^2 {R_2}^2}$$ or

(Equation 12) $$R_2 = 2\omega L$$

and

(Equation 13) $$C = \frac{1}{2\omega^2 L}$$

This is the condition that has to be fulfilled to get maximum active power from the voltage source in question. Then there is no reactive power from the voltage source (Z is quite resistive) and R_2 is as low as possible.

Putting (Equation 12) and (Equation 13) into (Equation 3) gives:

$$Z = R_1 + j\omega L + \frac{\frac{1}{j\omega C}\cdot R_2}{\frac{1}{j\omega C} + R_2} = R_1 + j\omega \cdot \frac{R_2}{2\omega} + \frac{\frac{R_2}{j\omega \cdot \frac{1}{2\omega^2 \frac{R_2}{2\omega}}}}{\frac{1}{j\omega \cdot \frac{1}{2\omega^2 \frac{R_2}{2\omega}}} + R_2}$$

and after some simplifications:

(Equation 14) $$Z = R_1 + \frac{R_2}{2}$$ or assuming $R_1 << R_2$

(Equation 15) $$Z \approx \frac{R_2}{2}$$

<u>Conclusion regarding parallel compensation</u>:

Compensation capacitans: $C = \frac{1}{2\omega^2 L}$ (according to (Equation 13))

Where ω is the electric angle speed according to (Equation 2) and L is the stator coil inductance. If (Equation 13) is satisfied then the stator coil load is quite resistive according to (Equation 14) or (Equation 15).

4 SERIES COMPENSATION

The following is a circuit analysis regarding the equivalent circuit of a stator coil in combination with series compensation. The question that should has it's answer is: "what conditions should be fulfilled to get maximum active power from the stator coils".

Figure 4 gives the principle for the series compensation.

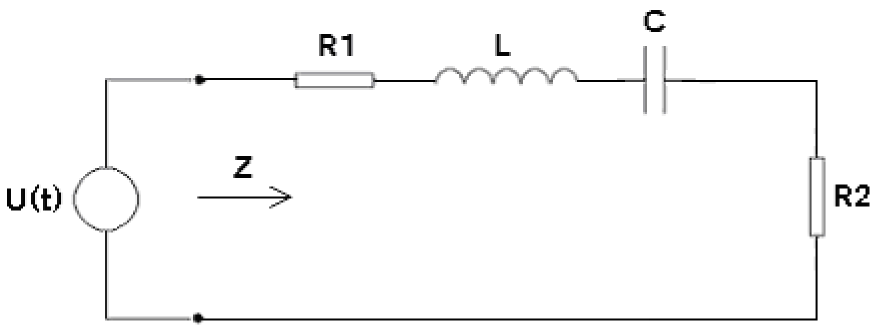

Figure 4 The principle of the series compensation. U(t): induced voltage in the coil, R1: coil resistance, R2: load resistance (it is assumed a resistive load), L: coil inductance, C: capacitance for compensation

The impedance Z in the circuit is:

(Equation 16) $$Z = R_1 + R_2 + j\omega L + \frac{1}{j\omega C}$$

For maximum compensation the phase angle of Z should be zero.

This implies $j\omega L + \frac{1}{j\omega C} = 0$ or

(Equation 17) $$C = \frac{1}{\omega^2 L}$$

If (Equation 17) is satisfied the impedance Z is quite resistive according to

(Equation 18) $$Z = R_1 + R_2$$

<u>Conclusion regarding series compensation</u>:

Compensation capacitans: $C = \frac{1}{\omega^2 L}$ (according to (Equation 17))

Where ω is the electric angle speed according to (Equation 2) and L is the stator coil inductance. If (Equation 17) is satisfied then the stator coil load is quite resistive according to (Equation 18).

5 COMPARISON BETWEEN PARALLEL AND SERIES COMPENSATION

A comparison is done between the two compensation principles by the following assumption:

- Power parameters are compared during different rotating speeds
- Complete compensation by a rotating speed, below named V_{rot}, of 80 rpm. This rotating speed is below named $\mathbf{V_{rot\_comp}}$.
- The current amplitude in a coil is for each rotating speed adapted to a maximum value with an upper limit. The adaption is performed by altering the value of the resistance R2, the load. The goal of the study is to get the maximum power available from the generator. Therefore the current amplitude is adjusted to a value that is not allowed to exceed that value, which was predicted in [1] (demagnetization current). If this value is exceeded there is a risk for damaging the permanent magnets by demagnetization. In [1] a maximum recommended value of about 14.5 A (amplitude) was predicted. As a limit for the calculations in this chapter a current amplitude of **14.5 A** therefore is chosen. This current limit is below named $\mathbf{I_{max}}$.
- The following circuit parameters are used:
  - R1: 1 Ω
  - R2: Controlled to get maximum allowed current
  - L: 106 mH
  - C: parallel compensation 116,7 μF (adapted for 80 rpm)
series compensation 233,4 μF (adapted for 80 rpm)
- The induced voltage is calculated according to the result presented in [1]
  i.e. u(t) = A · ω · cos ωt, where A is 1,615 (Vs) and $\omega = \frac{V_{rot} \cdot 2\pi \cdot P}{60}$
  ω is the electric angle speed, V_{rot} is the generator rotating speed (rpm) and P is the number of pole pairs (24) in the rotor. See Figure 17
- The impedance is calculated according to above (chapter 3 and chapter 4)
- Simulations have been performed by mathlab routines in accordance with A 3 Some results of simulations are presented in Figure 5 to Figure 17. The following could be noted:

- For low rotating speeds the P-comp (parallel compensation) is more effective than the S-comp (series compensation). See Figure 5. Mean value over the interval is about 6.5. For V_{rot} < about 56 rpm the P-comp is more effective than S-comp
- For low rotating speeds it could be a problem to reach I_{max} when using S-comp. See Figure 6, Figure 7 and Figure 8
  - Figure 6: For V_{rot} < about 56 rpm it is not possible to get I_{max} by S-comp
  - Figure 7**:** For V_{rot} < about 56 rpm the load resistance is zero for S-comp
- Within a sertain interval of rotating speed, below V_{rot_comp}, S-comp is more effective than P-comp. See Figure 9. In this example ($60 \leq V_{rot} \leq 80$) the active power relation between P-comp and S-comp is about 0,6. This means assuming a rectangular probability distribution in between the V_{rot} region in question, that in this case there is an increasing of active power by more than 60 % by using S-comp instead of P-comp
- For $V_{rot} > V_{rot\_comp}$ it is impossible to limit the current by increasing the load resistance, when using P-comp. This effect depends on the parallel capacitor that take more and more over the total current when the frequency is increasing. See Figure 14 and Figure 15. In Figure 16 it can be observed how the the real part of the impedance is decreasing when $V_{rot} > V_{rot\_comp}$ in spite of increased resistive load. The capacitor take more and more over when the frequency is increasing

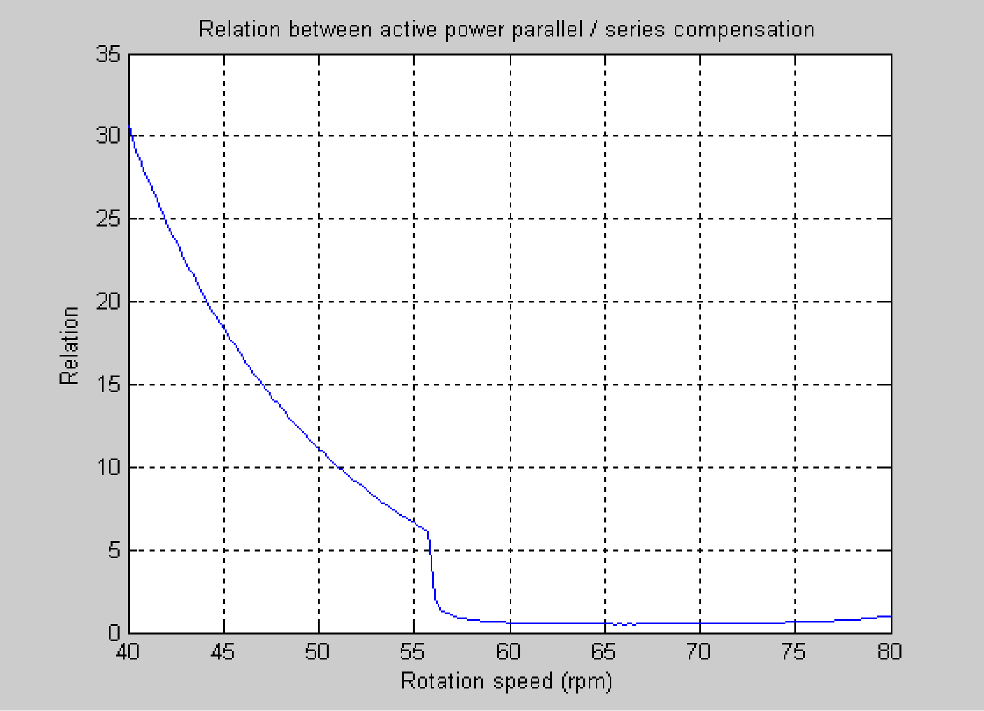

Figure 5 Relation between active power for P-comp/S-comp
Mean value over the interval is about 6.5
For V_{rot} < about 56 rpm the P-comp is more effective than S-comp

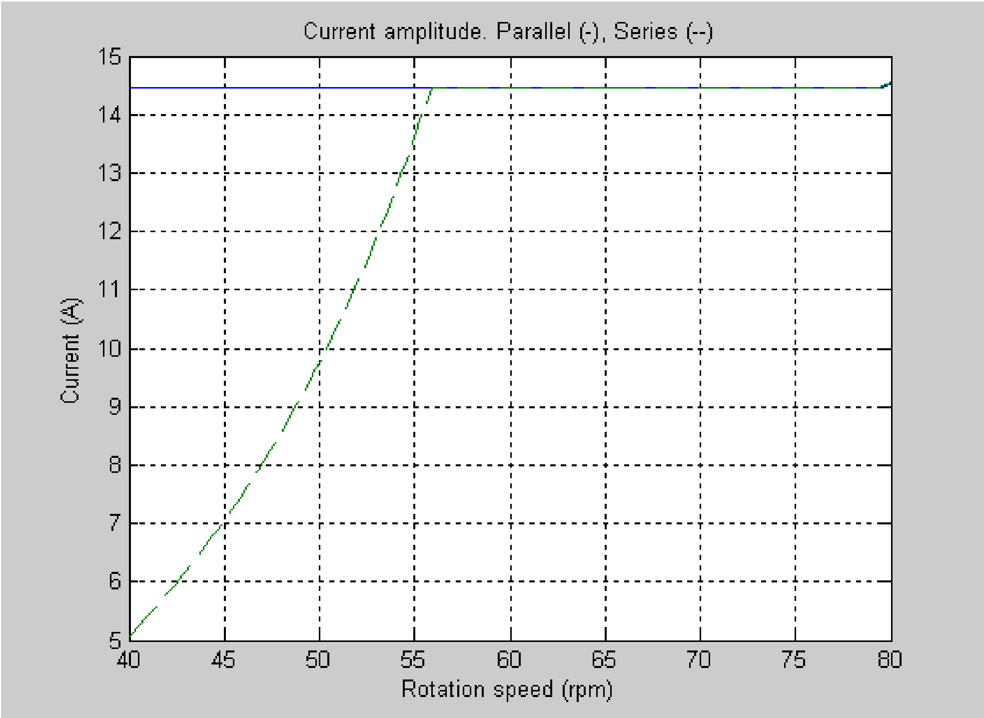

Figure 6 Current amplitude for P-comp and S-comp (- -)
For V_{rot} < about 56 rpm it is not possible to get I_{max} by S-comp

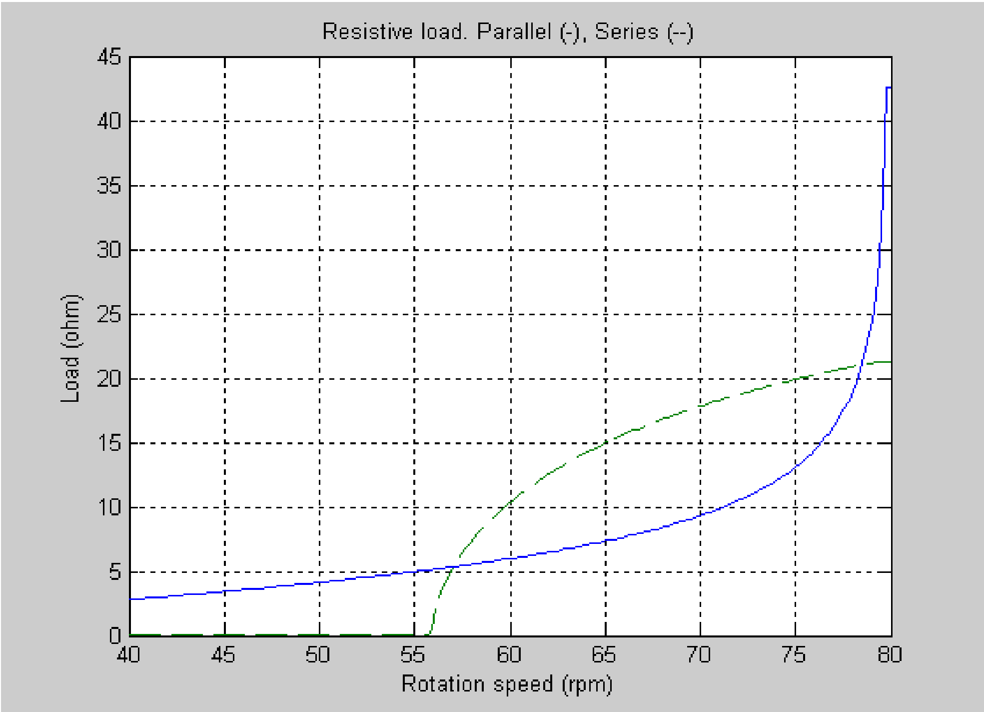

Figure 7 Adjusted load (resistive) for P-comp and S-comp (- -)
For V_{rot} < about 56 rpm the load resistance is zero for S-comp

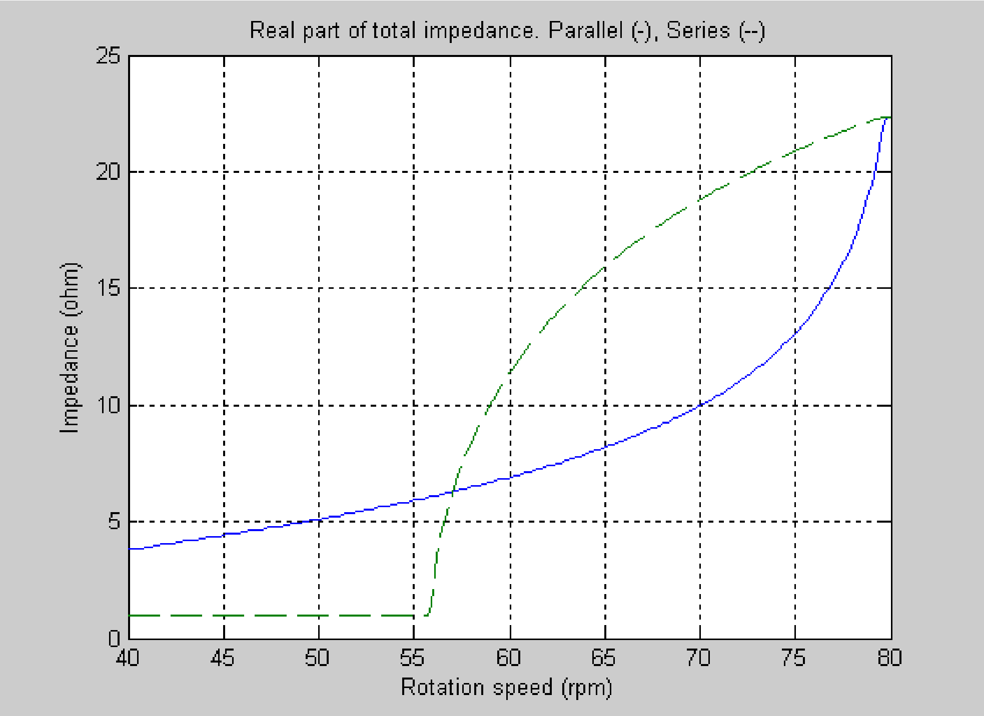

Figure 8 Real part of the total impedance for P-comp and S-comp (- -)

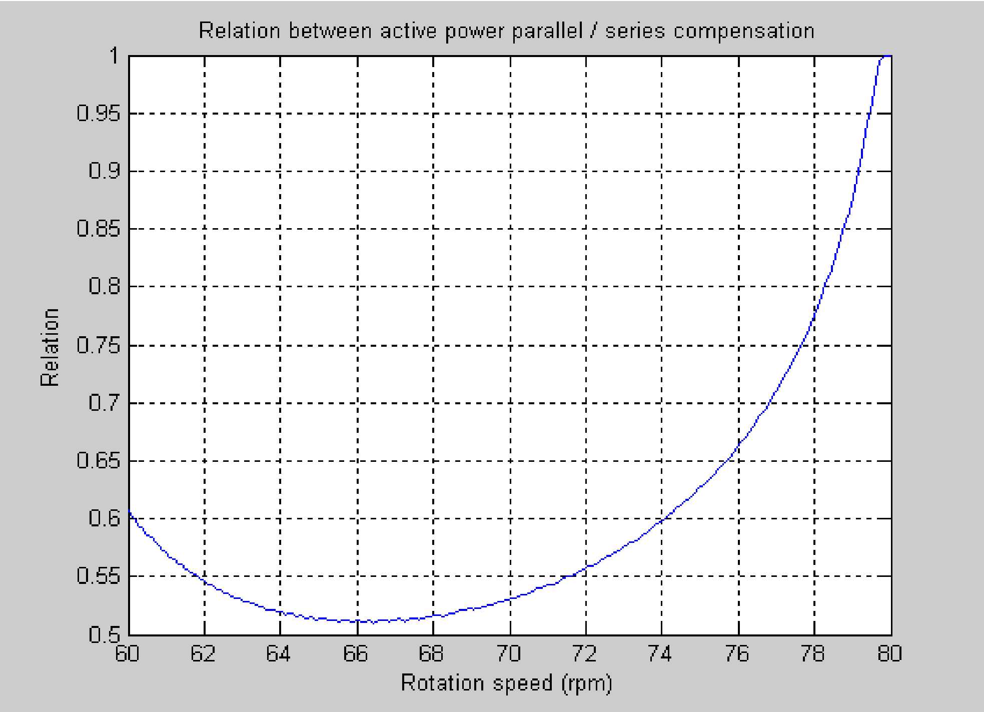

Figure 9 Relation between active power for P-comp/S-comp
Mean value over the interval is about 0.60
For V_{rot} < 80 rpm the S-comp is more effective than P-comp

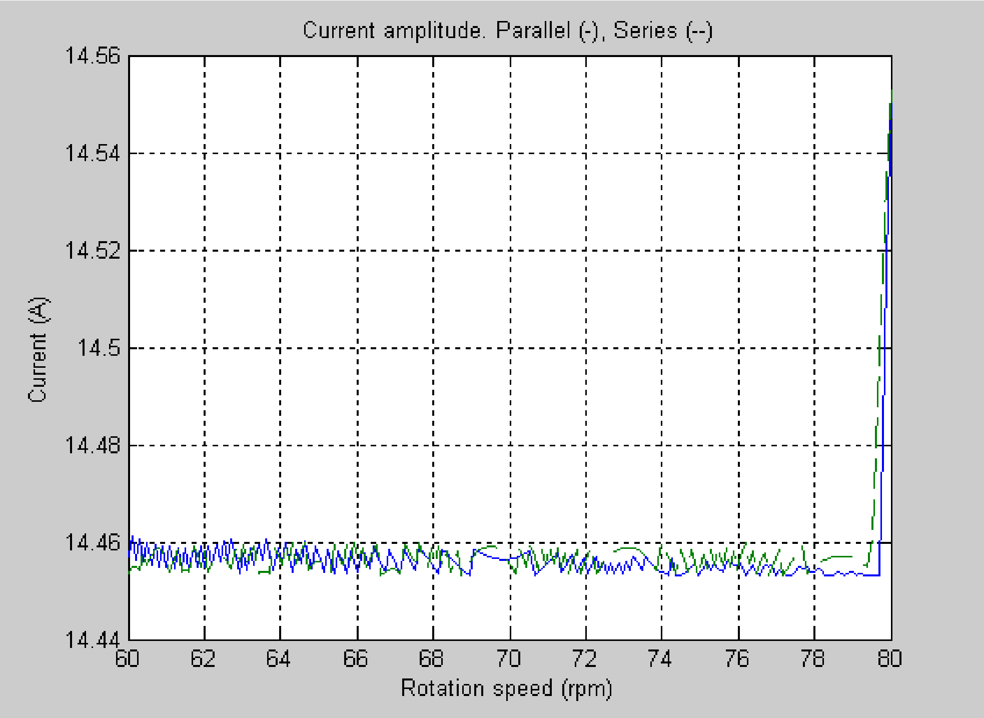

Figure 10 Current amplitude for P-comp and S-comp (- -). The current is adjusted to a value of about 14.5 A (amplitude)

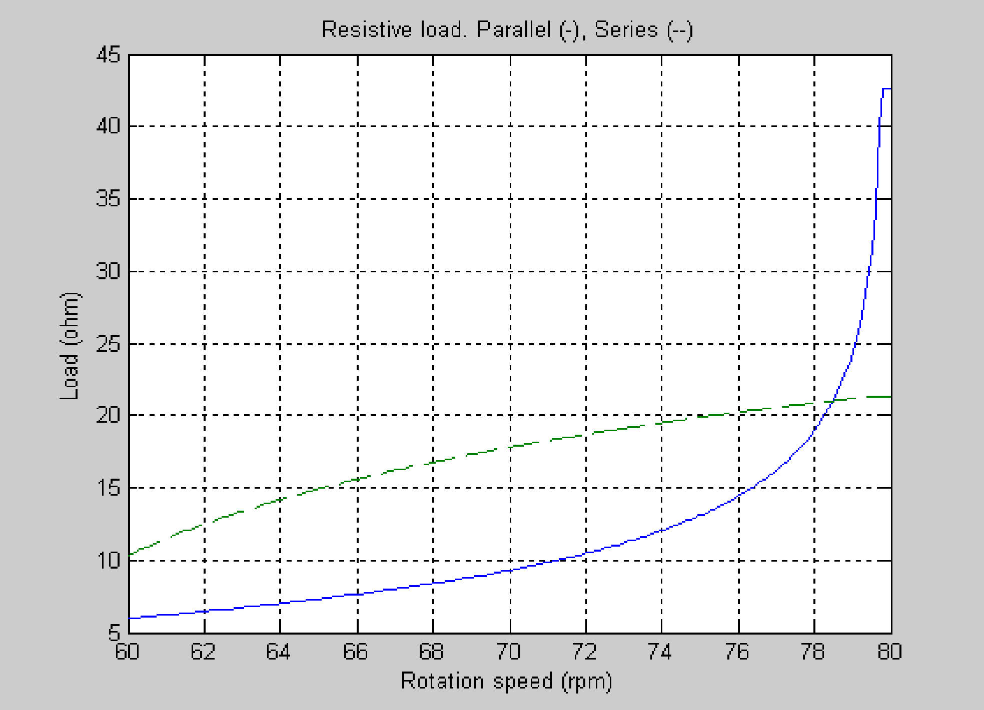

Figure 11 Adjusted load (resistive) for P-comp and S-comp (- -). The load is adjusted to result in a current of about 14.5 A (amplitude)

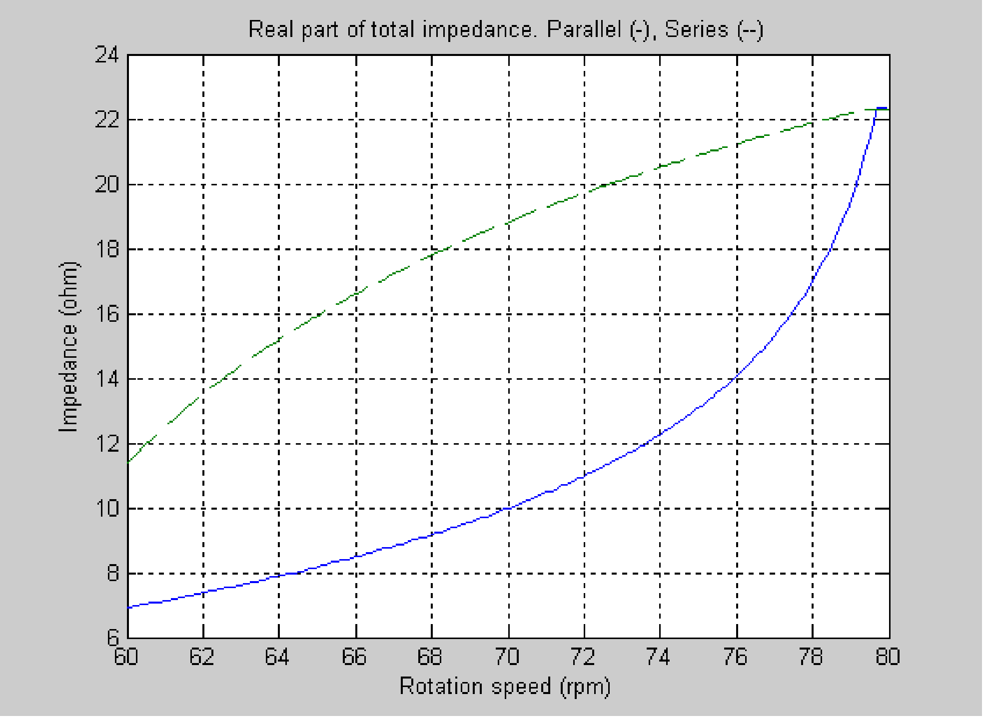

Figure 12 Real part of the total impedance for P-comp and S-comp (- -)

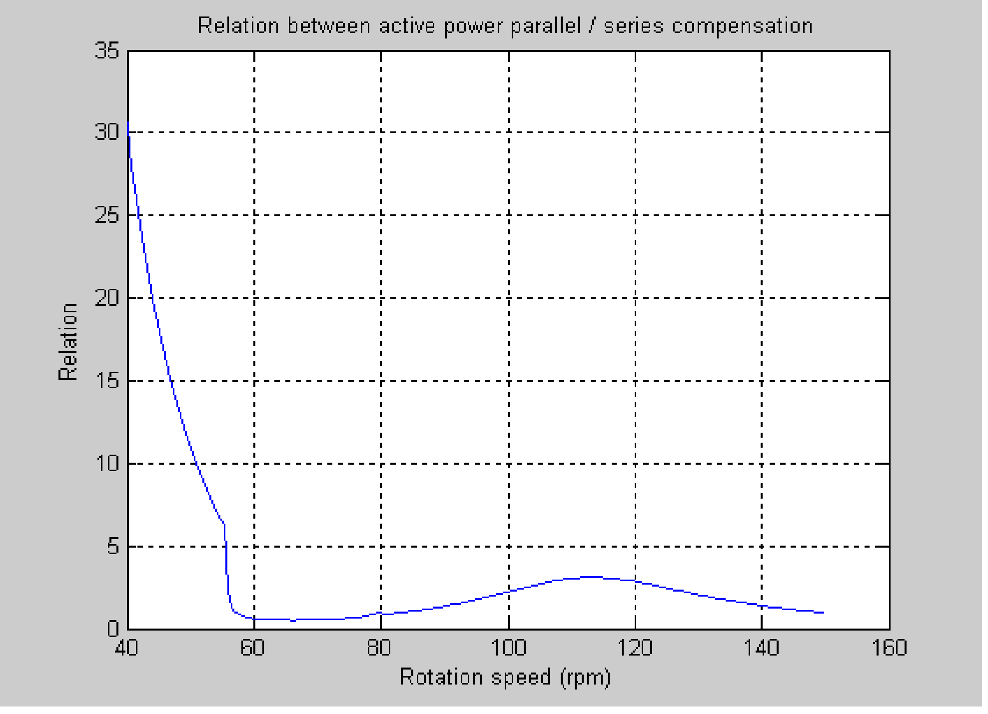

Figure 13 Relation between active power for P-comp/S-comp
For V_{rot} > about 80 rpm it is impossible to limit the current with P-comp

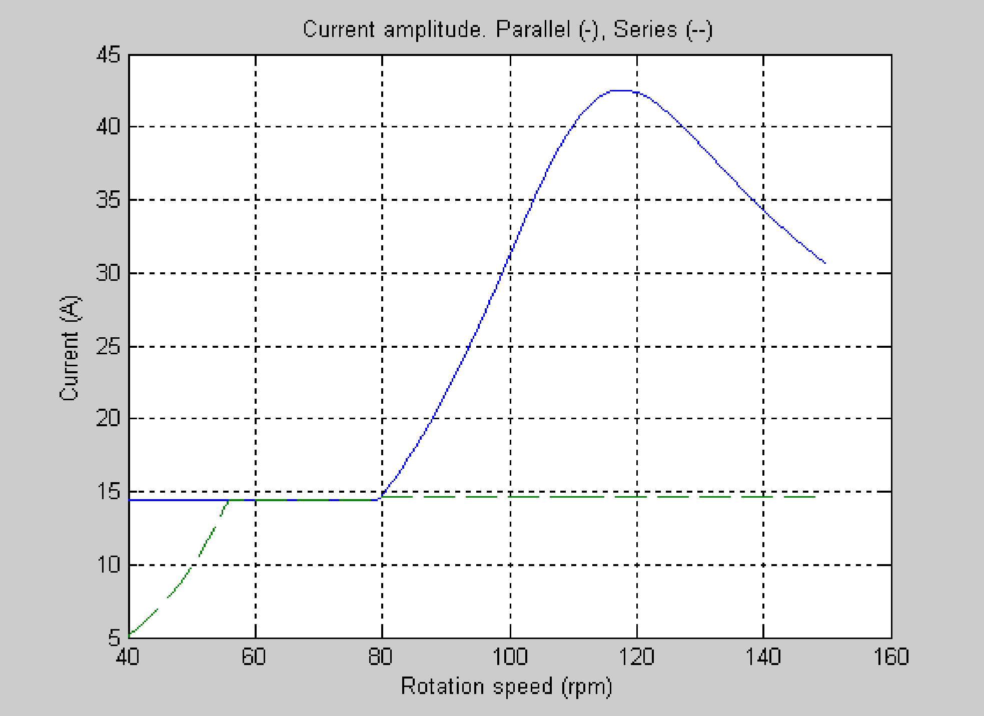

Figure 14 Current amplitude for P-comp and S-comp (- -)
For V_{rot} > about 80 rpm it is impossible to limit the current with P-comp

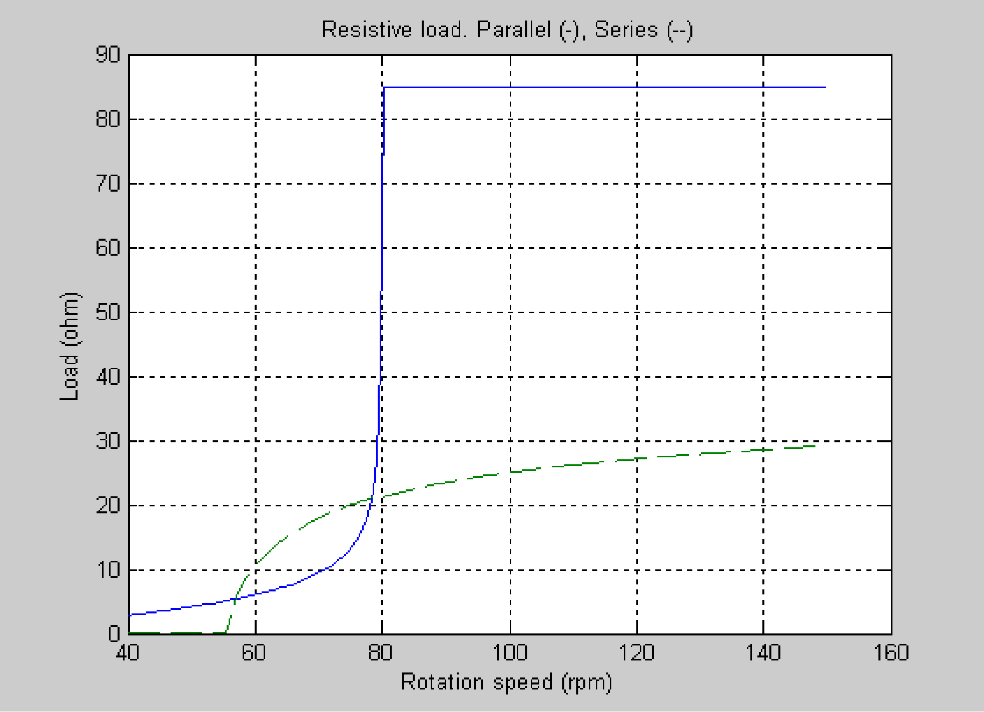

Figure 15 Adjusted load (resistive) for P-comp and S-comp (- -)
For V_{rot} > about 80 rpm it is impossible to limit the current with P-comp

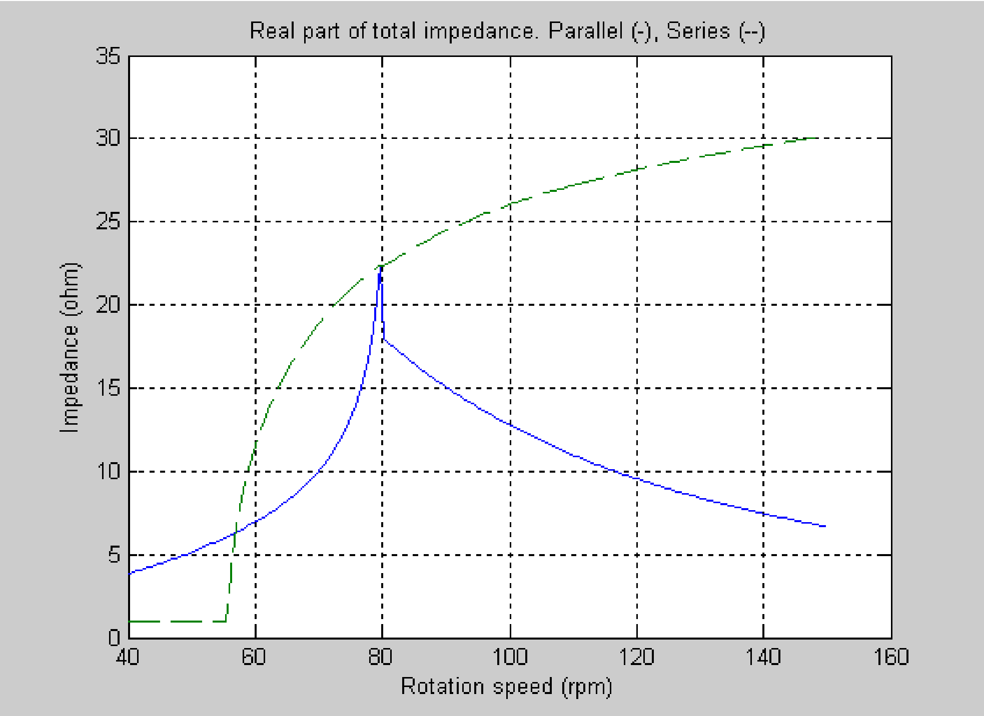

Figure 16 Real part of the total impedance for P-comp and S-comp (- -)
The real part is for the P-comp decreasing when V_{rot} > about 80 rpm, in spite of strongly increased resistive load

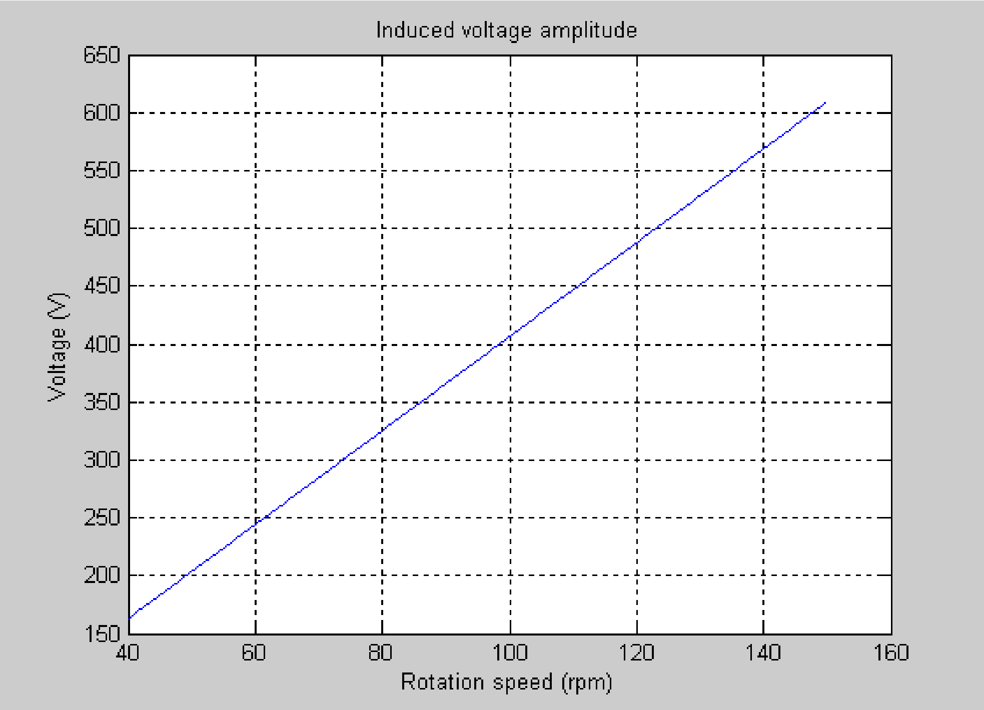

Figure 17 Induced voltage amplitude vs rotation speed

6 PRESENT DESIGN

The present generator design, that is based on parallel compensation, has a compensation capacitor of 60 μF. For a parallel compensation circuit there is a complete compensation at:

$$\omega = \frac{1}{\sqrt{2LC}}$$

That means a complete compensation at a rotation rate of:

$$V_{rot} = \frac{\omega \cdot 60}{2\pi \cdot P} = \frac{60}{2\pi\sqrt{2LC}\,24}$$

L = 0.106 H and C = 60 μF give

$V_{rot} \approx 112$ rpm

Figure 18 - Figure 25 illustrate some simulation results based on C and L parameters according to the present design (with P-comp) and by adapting R2 (the load) to get maximum allowed current amplitude (if possible), I_{max}, for each rotating speed. Note! In the present simulations and when compareing with the corresponding results with series compensation, V_{rot_comp} (complete compensation) for S-comp has been chosen to the same value as in chapter 5, i.e. at V_{rot_comp} = 80 rpm (the compensation capacitor is 233,4 μF). The following could then be noted:

- For P-comp it is now possible to limit the current amplitude to I_{max}, by adjusting the load resistance, if $V_{rot} \leq$ about 112 rpm. See Figure 19 and Figure 20. In Figure 21 it can be observed how the real part of the impedance is increasing up to V_{rot_comp} (112 rpm)
- If V_{rot} is studied in the interval 60 rpm to 80 rpm an extremely increasing of the effectivity for S-comp compared with P-comp can be noticed. See Figure 22. The result is, assuming a rectangular work distribution in between the V_{rot} region in question, that in this case there is a possibility to get 2,5 times more active power by using S-comp (note! V_{rot_comp} = 80 rpm for S-comp in this case) instead of P-comp (note! V_{rot_comp} = 112 rpm for P-comp in this case)

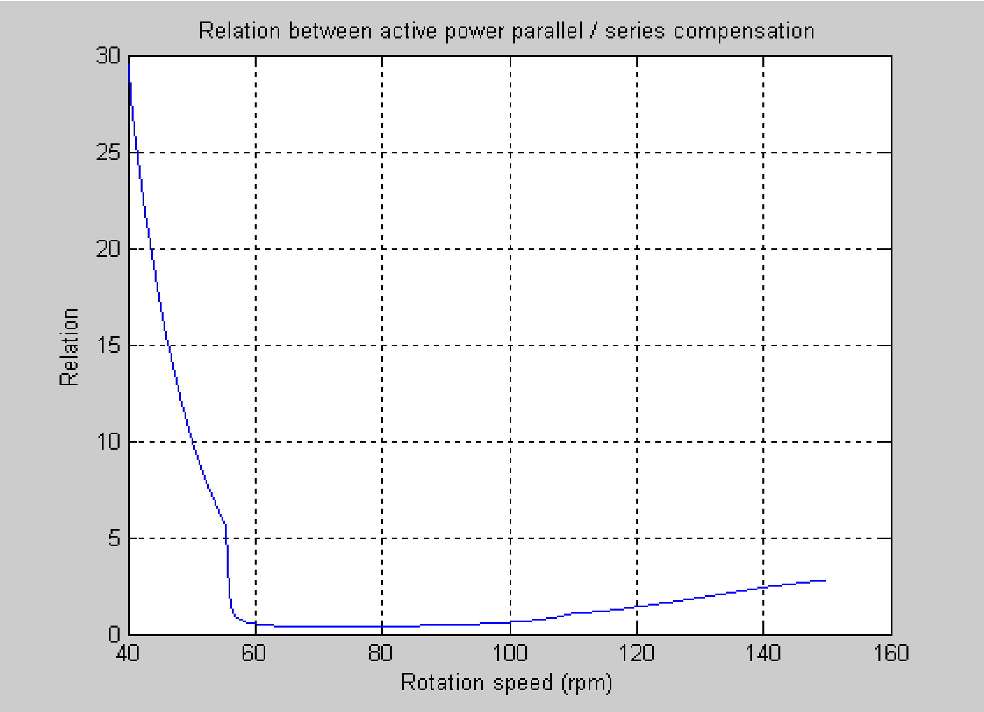

Figure 18 Relation between active power for P-comp/S-comp
For P-comp it is now possible to limit the current if $V_{rot} \leq$ about 112 rpm

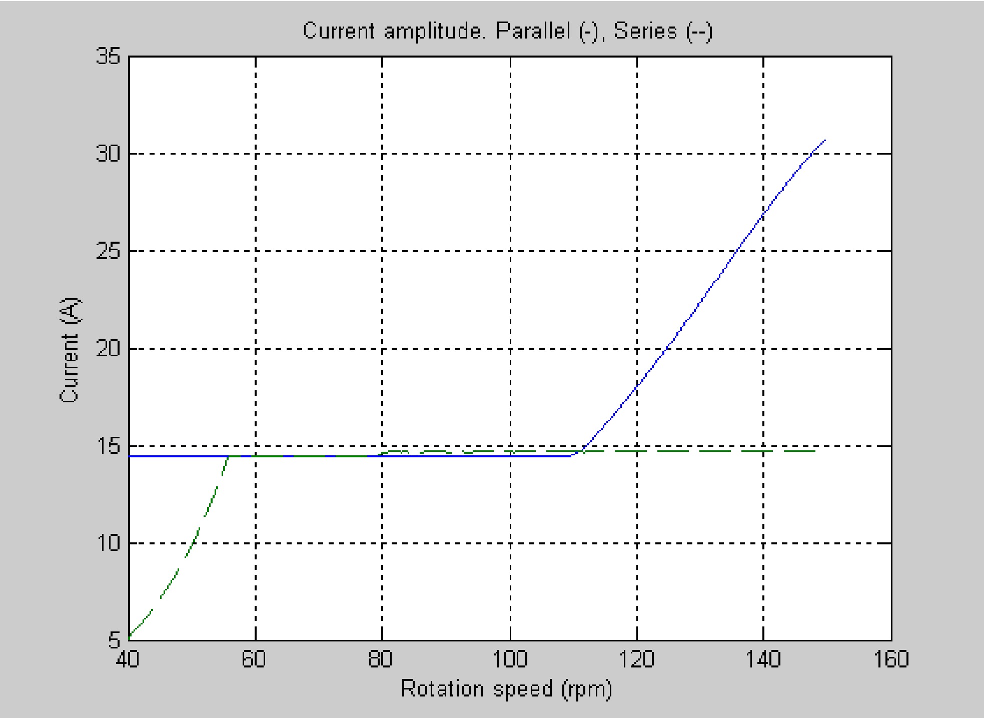

Figure 19 Current amplitude for P-comp and S-comp (- -)
For P-comp it is now possible to limit the current if $V_{rot} \leq$ about 112 rpm

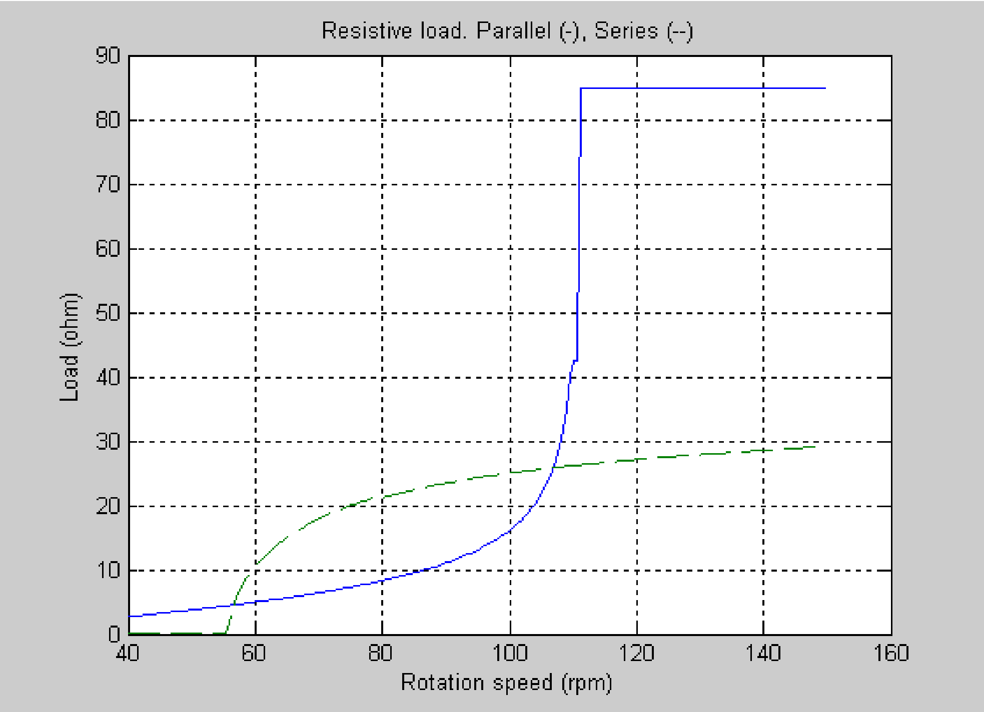

Figure 20	Adjusted load (resistive) for P-comp and S-comp (- -)
For P-comp it is now possible to limit the current for $V_{rot} \leq$ about 112 rpm

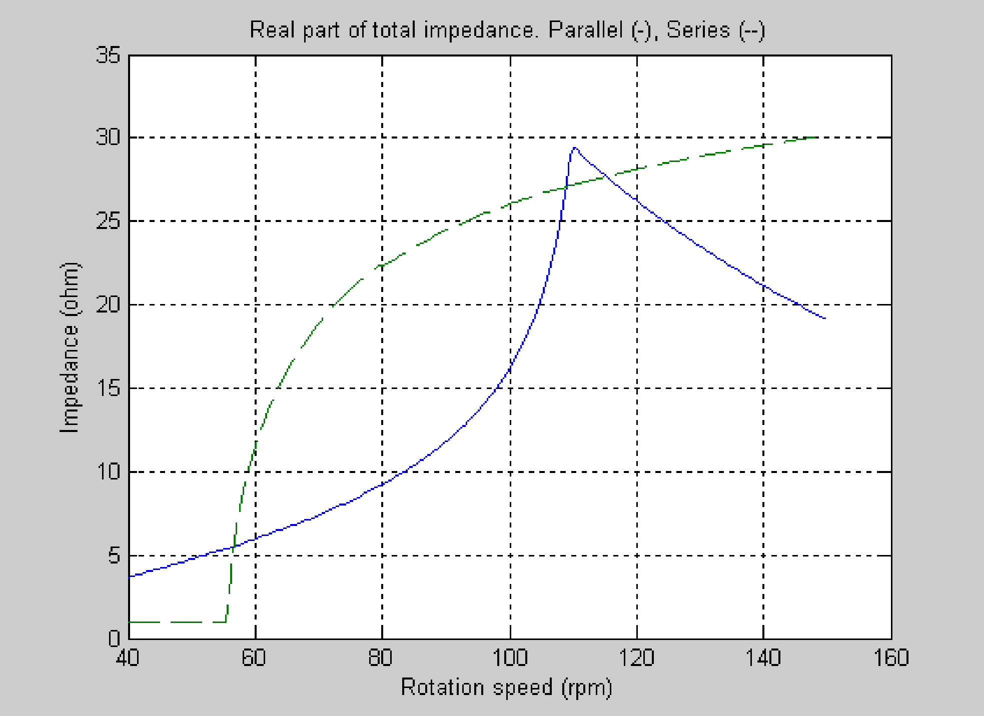

Figure 21	Real part of the total impedance for P-comp and S-comp (- -)
The real part is for the P-comp decreasing when V_{rot} > about 112 rpm, in spite of strongly increased resistive load

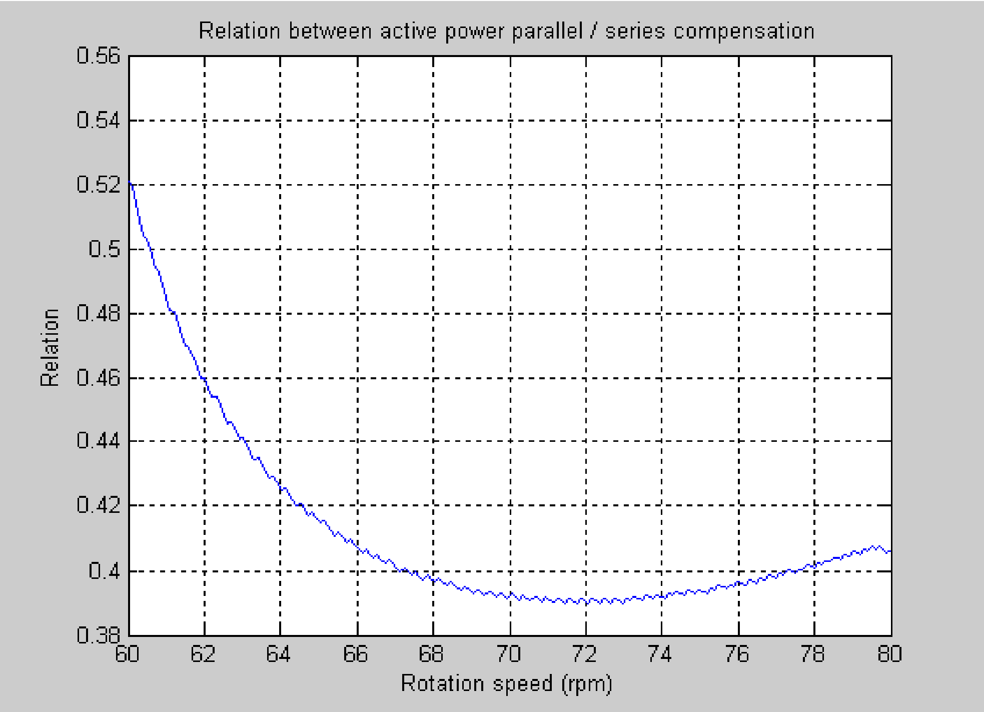

Figure 22 Relation between active power for P-comp/S-comp
Mean value over the interval is about 0.4

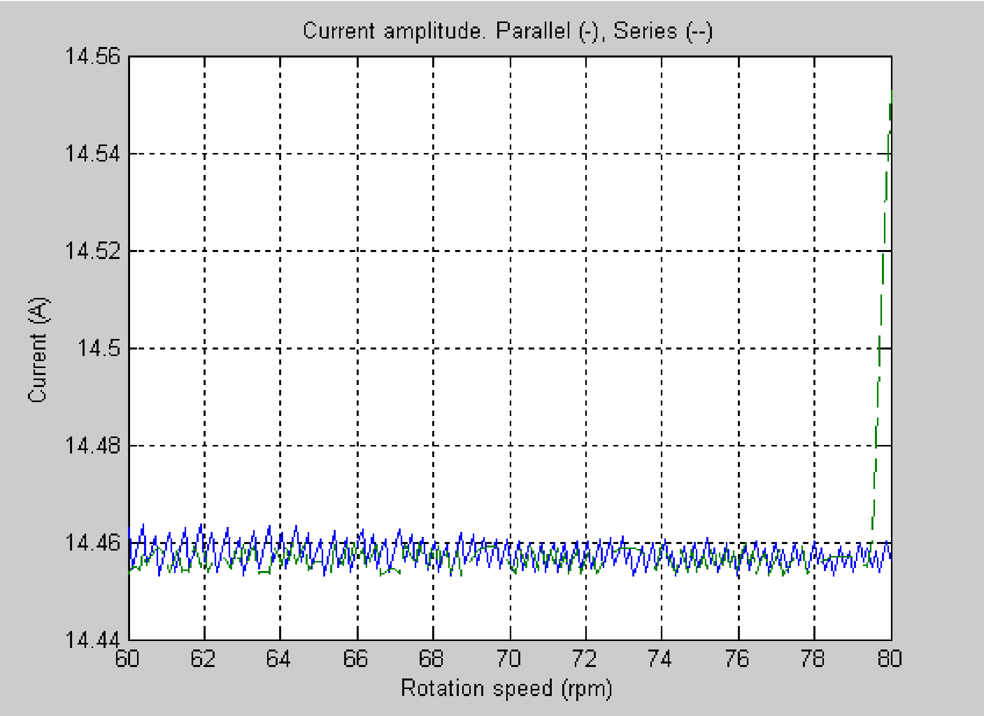

Figure 23 Current amplitude for P-comp and S-comp (- -)

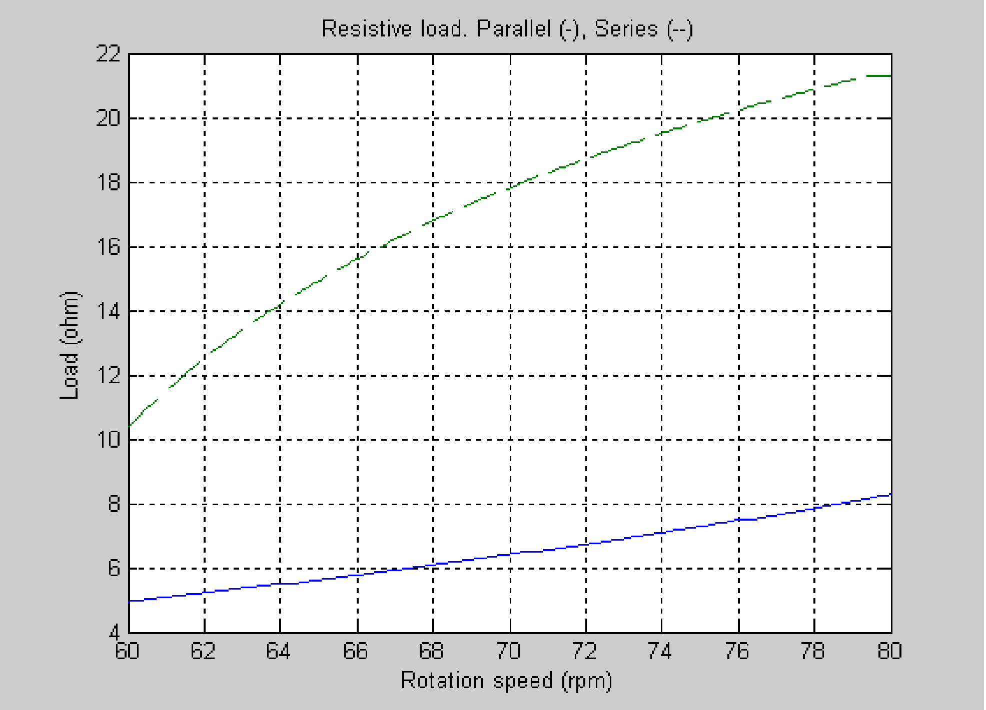

Figure 24 Adjusted load (resistive) for P-comp and S-comp (- -)

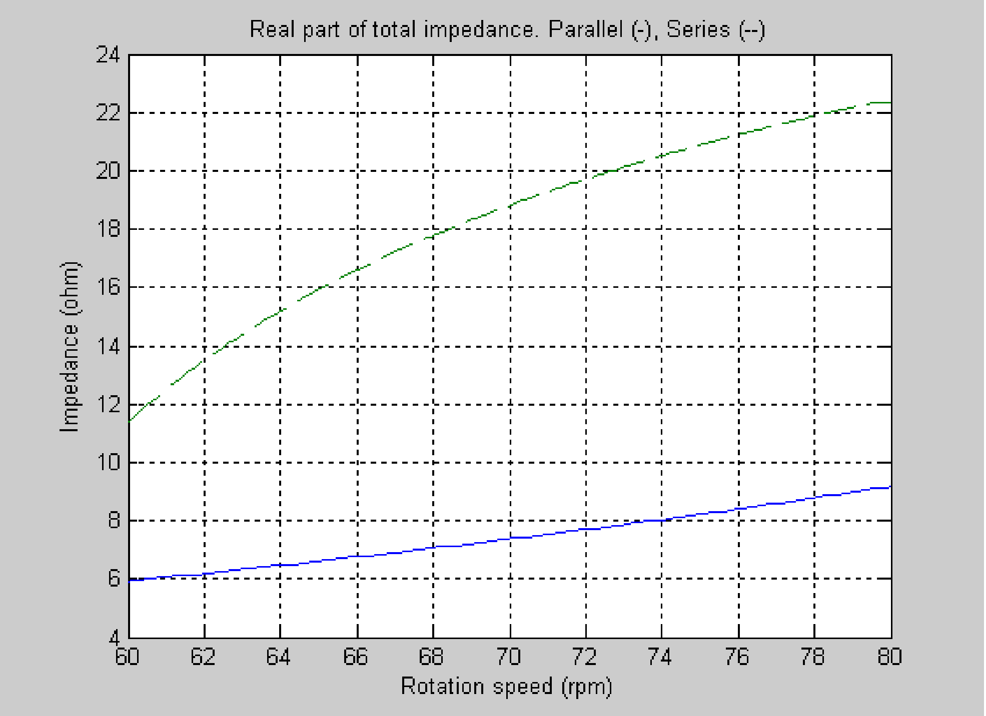

Figure 25 Real part of the total impedance for P-comp and S-comp (- -)

7 CONCLUSIONS

The following conclusions could be taken as a result of the analysis above:

- For large working areas in respect of V_{rot}*) it could be a problem to adjust the current amplitude by using the load. S-comp (series compensation) could result in problems for small V_{rot} values (problem to reach the wanted level) and P-comp (parallel compensation) could give problem for large V_{rot} values (problem to limit the wanted level). To get a basis for optimization of the best V_{rot_comp}**) and thereby choice of the compensating capacitors, furher studies regarding the probability distribution of the V_{rot} values have to be done. See chapter 8
- Depending on the choice of V_{rot_comp} , choice of working area in respect of V_{rot} and the probability distribution of the V_{rot} values in that working area, we could get very different answers with respect to the question of: "which compensating principle is the best one, S-comp or P-comp". The results above give a hint that probably the S-comp is to prefere. But more studies regarding the probability distribution of the V_{rot} values have to be done before we have a more specific answer. See chapter 8
- The used example in chapter 5 resulted among other things in: "Within a sertain interval of rotating speed, below V_{rot_comp}, we have that S-comp is more effective than P-comp. See Figure 9. In this example ($60 \leq V_{rot} \leq 80$) the active power relation between P-comp and S-comp is about 0,6. This means, if we assume a rectangular probability distribution in between the V_{rot} region in question, that we in this case have an increasing of active power by more than 60 % by using S-comp instead of P-comp".

*) V_{rot}: rotation speed of the generator (rpm)

**) V_{rot_comp}: the rotation speed that, with respect to compensation principle in question, gives perfect reactive compensation (no reactive power)

8 FUTURE WORK

Above there is suggested a study to investigate the statistical work/probability distribution of the different V_{rot}. This future work should include:

- Statistical studies regarding the wind speed
- Adapting the wind speed distribution to an optimal working area for V_{rot} with respect to λ-C_p and V_{rot_comp} for P-comp and S-comp

9 REFERENCES

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Chalmers, Juli 2003, Ingemar Mathiasson

[2] Laboratory Measurements of a 40 kW
Permanent Magnet Generator
Chalmers, December 1998, Ola Carlson and Anders Grauers

[3] Investigation of a Wind Power Generator. Part 1
Chalmers, Januari 2005, Ingemar Mathiasson

Appendix

A 1 Software. Parallel compensation

A matlab-routine called ”medel_p_kp_Dlast” has been used to simulate the circuit for parallel compensation. The routine controls the current amplitude to a specific value in between the rotation speed region that is to be studied. The control is realized by adapting the load (resistive) to an appropriate level. Some parameters are loaded in the file "fil_parkomp" for later use.

```
%
%   medel_p_kp_Dlast
%

%   Reglerar utgående strömamplitud från en generatormodul till önskad
%   nivå inom valfritt varvtalsintervall. Reglering sker genom att anpassa

%   lasten som förusätts resistiv. Kompensering map reaktiv effekt sker med
%   parallellkompensation. Lagring av vissa beräkningsparametrar görs i
%   filen "fil_parkomp"
%
%
%   Ingemar Mathiasson,  Januari 2005
%
%
    clear
%
    R1=1.;        % spolresistans
%    R2=39.9611;      % lastresistans anpassad för 75 rpm
    R2=42.6251;      % lastresistans anpassad för 80 rpm
```

```
   L=0.106;    % spolinduktans
%    C=1.3276e-004;  % kompensationskapacitans anpassad för 75 rpm
%   C=1.1668e-004;   % kompensationskapacitans anpassad för 80 rpm
   C=60.e-006;      % kompensationskapacitans enligt dagens design
   A=1.615;    % amplitud för avlänkat spolflöde
%    Imax=15.2360;   % maximalt tillåten spolström
   Imax=14.5530;   % maximalt tillåten spolström
%    Imax=12.;   % maximalt tillåten spolström
   DR2=0.05;        % stegning av R2 vid anpassning av last

%
   rpm=75;     % rotationshastighet (nominell)
   rpm=60;     % rotationshastighet
%
   N_sampel=200;       % antal rotationssampel
%
   rpm_min=60;   % lägsta rotationsfrekvens
   rpm_max=80;   % högsta rotationsfrekvens
%
   rpm_steg=(rpm_max-rpm_min)/(N_sampel-1);    % sampelsteg
%
   for k=1:N_sampel
   rpm(k)=rpm_min+(k-1)*rpm_steg;     % aktuell rotationsfrekvens
   w(k)=rpm(k)/60*24*2*pi;   % vinkelfrekvens för inducerad spänning
   R2=42.6251;      % lastresistans anpassad för 80 rpm
%    R2=39.9611;      % lastresistans anpassad för 75 rpm
```

```
%    R2_var(k)=2*w(k)*L;   % varierbar lastresistans anpassad till aktuell rotationsfrekvens

   C_var(k)=1/(2*w(k)*w(k)*L);  % varierbar kompensationskapacitans anpassad till aktuell rotationsfrekvens

%

   U(k)=A*w(k);      % inducerade spänningens ampliud

%

   for m1=1:5000

%

   Z(k)=R1+j*w(k)*L+(R2/(j*w(k)*C))/(1/(j*w(k)*C)+R2);     % Impedans


   I(k)=U(k)/abs(Z(k));

   if I(k) < Imax-0.1

      R2=R2-DR2;

      if R2 < 0, R2=0.01;, end

   else

     break

   end

   end

%

   for m1=1:5000


  Z(k)=R1+j*w(k)*L+(R2/(j*w(k)*C))/(1/(j*w(k)*C)+R2);     % Impedans

   I(k)=U(k)/abs(Z(k));

   if I(k) > Imax+0.1

      R2=R2+DR2;

      if R2 > 85, R2=85;, end
```

```
   else
      break
   end
   end
%
   I(k)=U(k)/abs(Z(k));     % amplitud för utgående ström
   R2_var(k)=R2;            % resistiv last
   Z_var(k)=Z(k);           % total impedans
   Z_var_R(k)=real(Z(k));     % reell del av total impedans

   fi(k)=atan(imag(Z(k))/real(Z(k)));     % kretsens fasvinkel
   P(k)=U(k)^2/abs(Z(k))/2*cos(fi(k));     % aktiv effekt enskild statormodul
   Q(k)=U(k)^2/abs(Z(k))/2*sin(fi(k));     % reaktiv effekt enskild statormodul
   Ptot(k)=27*P(k);                 % aktiv effekt enskild statormodul
   Qtot(k)=27*Q(k);                 % reaktiv effekt enskild statormodul
%
   end
%
   save fil_parkomp Ptot Qtot I R2_var Z_var_R rpm       % lagra aktiv och reaktiv
effekt i filen "fil_parkomp"
%
   figure(1)
   plot(rpm,P), grid
%
%   Sök medeleffekter
%
```

```
   Pmedel=mean(P);         % medeleffekt för modul

   Ptot_medel=mean(Ptot);      % medeleffekt för generator

%

%

%   STOP
```

A 2 Software. Series Compensation

A matlab-routine called ”medel_p_ks_Dlast” has been used to simulate the circuit for series compensation. The routine controls the current amplitude to a specific value in between the rotation speed region that is to be studied. The control is realized by adapting the load (resistive) to an appropriate level. Some parameters are loaded in the file "fil_parkomp" for later use.

```
%

%   medel_p_ks_Dlast

%

%   Reglerar utgående strömamplitud från en generatormodul till önskad

%   nivå inom valfritt varvtalsintervall. Reglering sker genom att anpassa

%   lasten som förusätts resistiv. Kompensering map reaktiv effekt sker med

%   seriekompensation. Lagring av vissa beräkningsparametrar görs i

%   filen "fil_serkomp"

%

%

%   Ingemar Mathiasson,  Januari 2005

%

%

   clear

%
```

```
   R1=1.;      % spolresistans
%    R2=39.9611/2;      % lastresistans anpassad för 75 rpm
   R2=42.6251/2;      % lastresistans anpassad för 80 rpm
   L=0.106;    % spolinduktans
%    C=2.6552e-004;  % kompensationskapacitans anpassad för 75 rpm
   C=2.3336e-004;   % kompensationskapacitans anpassad för 80 rpm

%    C=120.e-006;      % kompensationskapacitans med motsv kompensations frekvens
som dagens design
   A=1.615;    % amplitud för avlänkat spolflöde
%    Imax=15.2360;   % maximalt tillåten spolström
    Imax=14.5530;   % maximalt tillåten spolström
%    Imax=9.;   % maximalt tillåten spolström
   DR2=0.01;        % stegning av R2 vid anpassning av last
%
   rpm=75;     % rotationshastighet (nominell)
   rpm=30;     % rotationshastighet
%
   N_sampel=200;       % antal rotationssampel
%
   rpm_min=60;   % lägsta rotationsfrekvens
   rpm_max=80;   % högsta rotationsfrekvens
%
   rpm_steg=(rpm_max-rpm_min)/(N_sampel-1);    % sampelsteg
%
   for k=1:N_sampel
```

```
    rpm(k)=rpm_min+(k-1)*rpm_steg;     % aktuell rotationsfrekvens
    w(k)=rpm(k)/60*24*2*pi;   % vinkelfrekvens för inducerad spänning
%    R2=39.9611/2;      % lastresistans anpassad för 75 rpm
    R2=42.6251/2;      % lastresistans anpassad för 80 rpm
%    R2_var(k)=2*w(k)*L;   % varierbar lastresistans anpassad till aktuell
rotationsfrekvens


    C_var(k)=1/(w(k)*w(k)*L);  % varierbar kompensationskapacitans anpassad till
aktuell rotationsfrekvens
%
    U(k)=A*w(k);      % inducerade spänningens ampliud
%
    for m1=1:5000
%
    Z(k)=R1+j*w(k)*L+1/(j*w(k)*C)+R2;     % Impedans
    I(k)=U(k)/abs(Z(k));
    if I(k) < Imax-0.1
        R2=R2-DR2;
        if R2 < 0, R2=0.01;, end
    else
       break
    end
    end
%
    for m1=1:5000
```

```
  Z(k)=R1+j*w(k)*L+1/(j*w(k)*C)+R2;     % Impedans
   I(k)=U(k)/abs(Z(k));
   if I(k) > Imax+0.1
      R2=R2+DR2;
      if R2 > 85, R2=85;, end
  else
       break
   end
   end
%
   I(k)=U(k)/abs(Z(k));     % amplitud för utgående ström
   R2_var(k)=R2;            % resistiv last
   Z_var(k)=Z(k);           % total impedans
   Z_var_R(k)=real(Z(k));     % reell del av total impedans
   fi(k)=atan(imag(Z(k))/real(Z(k)));     % kretsens fasvinkel
   P(k)=U(k)^2/abs(Z(k))/2*cos(fi(k));     % aktiv effekt enskild statormodul
   Q(k)=U(k)^2/abs(Z(k))/2*sin(fi(k));     % reaktiv effekt enskild statormodul
   Ptot(k)=27*P(k);                 % aktiv effekt enskild statormodul
   Qtot(k)=27*Q(k);                 % reaktiv effekt enskild statormodul
%
   end
%
   save fil_serkomp Ptot Qtot I R2_var Z_var_R rpm       % lagra aktiv och reaktiv
effekt i filen "fil_serkomp"
%
```

```
   figure(1)
   plot(rpm,P), grid
%
%  Sök medeleffekter
%
   Pmedel=mean(P);        % medeleffekt för modul

   Ptot_medel=mean(Ptot);      % medeleffekt för generator
%
%
%  STOP
```

A 3 Software. Comparison Parallel / Series Compensation

A matlab-routine called ” komp_par_ser” has been used to compare the performance between parallel compensation and seires compensation. The routine uses parameters that are loaded in the files "fil_parkomp" (performance of parallel compensation) and "fil_serkomp" (performance of series compensation). This routine is preceded by the routines ”medel_p_kp_Dlast” and ”medel_p_ks_Dlast”.

```
%
%  komp_par_ser
%
%  Gör olika jämförelser rörande prestanda hos parallell- resp
%  seriekompensering. Utnyttjar filerna "fil_parkomp" resp "fil_serkomp".
%  Programmet föregås av körningar med programmen "medel_p_kp_Dlast" resp
%  "medel_p_kp_Dlast"
%
%  Ingemar Mathiasson,  Januari 2005
%
```

```
%
    clear
%
    load fil_parkomp        % hämta aktiv och reaktiv effekt avseende
parallellkompensering
    Ptot_par=Ptot;

    Qtot_par=Qtot;
    I_par=I;
    R2_var_par=R2_var;
    Z_var_R_par=Z_var_R;
%
    clear Ptot Qtot I R2_var Z_var_R
%
    load fil_serkomp        % hämta aktiv och reaktiv effekt avseende seriekompensering
    Ptot_ser=Ptot;
    Qtot_ser=Qtot;
    I_ser=I;
    R2_var_ser=R2_var;
    Z_var_R_ser=Z_var_R;
%
    Prel=Ptot_par./Ptot_ser;      % relation mellan aktiv effekt för par-komp och ser-komp
    Qrel=Qtot_par./Qtot_ser;      % relation mellan reaktiv effekt för par-komp och ser-
komp
    Irel=I_par./I_ser;            % relation mellan ström för par-komp och ser-komp
%
    Prel_medel=mean(Prel);        % medelvärde över aktuellt rotationsintervall
```

```
   Qrel_medel=mean(Qrel);       % medelvärde över aktuellt rotationsintervall

   Irel_medel=mean(Irel);       % medelvärde över aktuellt rotationsintervall

%

   figure(1)

   plot(rpm,Prel), grid, title('Relation between active power parallel / series compensation'), xlabel('Rotation speed (rpm)'), ylabel('Relation')


%    figure(2)

%    plot(rpm,Qrel), grid, title('Relation between reactive power parallel / series compensation'), xlabel('Rotation speed (rpm)'), ylabel('Relation')

%    figure(3)

%    plot(rpm,Irel), grid, title('Relation between current parallel / series compensation'), xlabel('Rotation speed (rpm)'), ylabel('Relation')

   figure(4)

   plot(rpm,I_par,'-',rpm,I_ser,'--'),grid, title('Current amplitude. Parallel (-), Series (--)'), xlabel('Rotation speed (rpm)'), ylabel('Current (A)')

   figure(5)

   plot(rpm,R2_var_par,'-',rpm,R2_var_ser,'--'),grid, title('Resistive load. Parallel (-), Series (--)'), xlabel('Rotation speed (rpm)'), ylabel('Load (ohm)')

   figure(6)

   plot(rpm,Z_var_R_par,'-',rpm,Z_var_R_ser,'--'),grid, title('Real part of total impedance. Parallel (-), Series (--)'), xlabel('Rotation speed (rpm)'), ylabel('Impedance (ohm)')

%

%

%   STOP
```