Study of Some Characteristics of the Thyristor System for Synchronous Machine Drive or Generator.Without Transformers

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Abstract

Synchronous machines working under conditions of high range variable torque (wind and substream generators, oil pumps etc.) demands a special approach to solve problem of automatic control of voltage and current of exciting systemin response to change of the torque. Solution of this problem brings optimal operation conditions to the syncronous machine for the above mentioned regimes and improves technical and economical figures of the main network.

Introduction

Development in the semiconductor technology replaced the old control systems(based on special hybrid transformers) with powerfull semiconductor (thyristor etc.) technique. Different types of thyristor controled rectifiers are peresent in technical literature[1] and it is possible to choose any suitable system depending upon the application: High efficiency and no inertia is necessary, good overloading ability, higher reliability, very small sized systems etc. A new cheaper rectifier with lower distortion factor was designed to feed and provide smooth control of exciting system.

It is important to study all problems during design and study of different semiconductor system for automatic control of synchronous machine to be able to get full pictures of voltages and currents that may appear at any circumstances at any regime for very low to overload on the shaft.

This paper is presenting, study and p-spice analysis results of one perspective diagram of automatic exciting system of synchronous machine designed for a high range variable torque on the shaft.

Usually exciting voltage regime variations are around ±10-15% of rated value. During sudden voltage drop in the main due to distant short circuits the voltage should be forced up to 1.5 V_n to be able to keep this machine in stable work with the main. For such cases a special type of rectifier is necessary to provide smooth control during normal dynamic regime cosΦ=1 and to provide instant force to give almost double rated current.

Designed System

The diagram of proposed design is given in figure 1

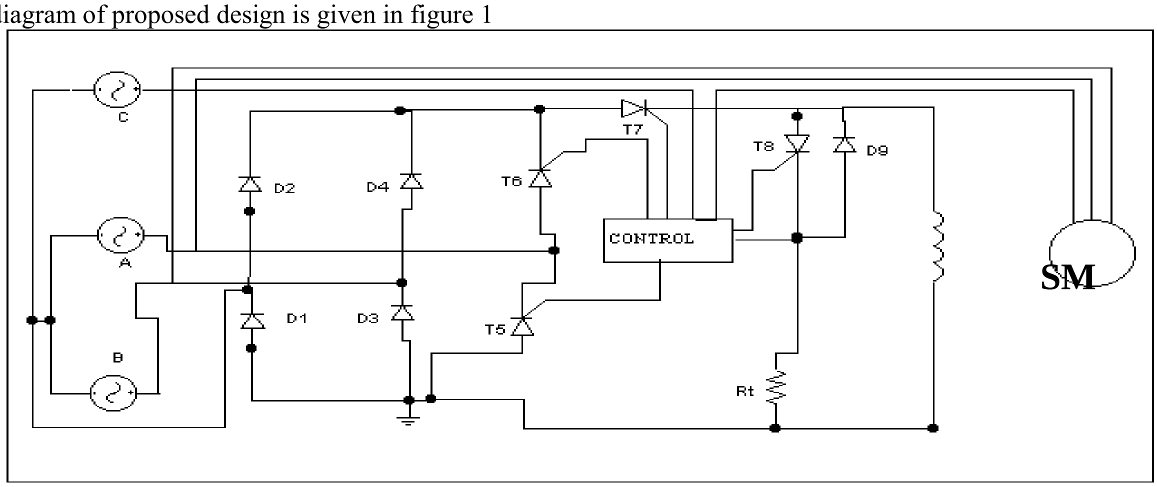

Figure 1 Diagram of low distortion rectifier

It consists of four diodes bridge that is connected between phase B and neutral but two additional thyristors parallel to bridge are connected to phase A from the common point.

The designed diagram works as the follows

At the first glance it looks obvious that when thyristors T5 and T6 are fully open α=0 bridge of D3,D4,T5,T6 works (under line voltage) and provides $\sqrt{3}$ V_n forced rectified voltage to the exciting coil.. When˜ α=0 the force voltage is higher than 1.73 V_n and it reaches1.87 $V_n > \sqrt{3}$ V_n because voltage $|V_{AB}|$ is less than $|V_B|$ at the beginning and end of the pulse. Using Pspice model analyse the operating conditions of the designed rectifierwill be shown.

Up to some level of the torque, the exciting coil of the synchronous machine gets power from only one phase B bridge. As the torque and the current of the machine rise. Internal stator current sensor starts to form a signal to switch on thyristors T5 and T6. This signal depends on the amplitude of the synchronous current. It changes the firing angle α of the thyristors and in this way it controls the voltage value on the exciting coil proportional to the synchronous machine current. The two thyristors T7 and T8 and resistor R_T serves the drive for start up and enter the synchronism.
Let us consider the conditions of the work of this automatically controlled exciting system under normally cycling (variable) torque on the shaft (maximum frequency of the pulsing load not more than 0.3 Hz)
In figure 2 there are phase line and rectified voltages Due to absence of transformer the valve commutation acts almost practically instantaneously.

THE PSPICE MODELING ANALYSIS AND RESULTS
The converter is analyzed by the PSpice modeling software and the graphs in Figure 2 is obtained.

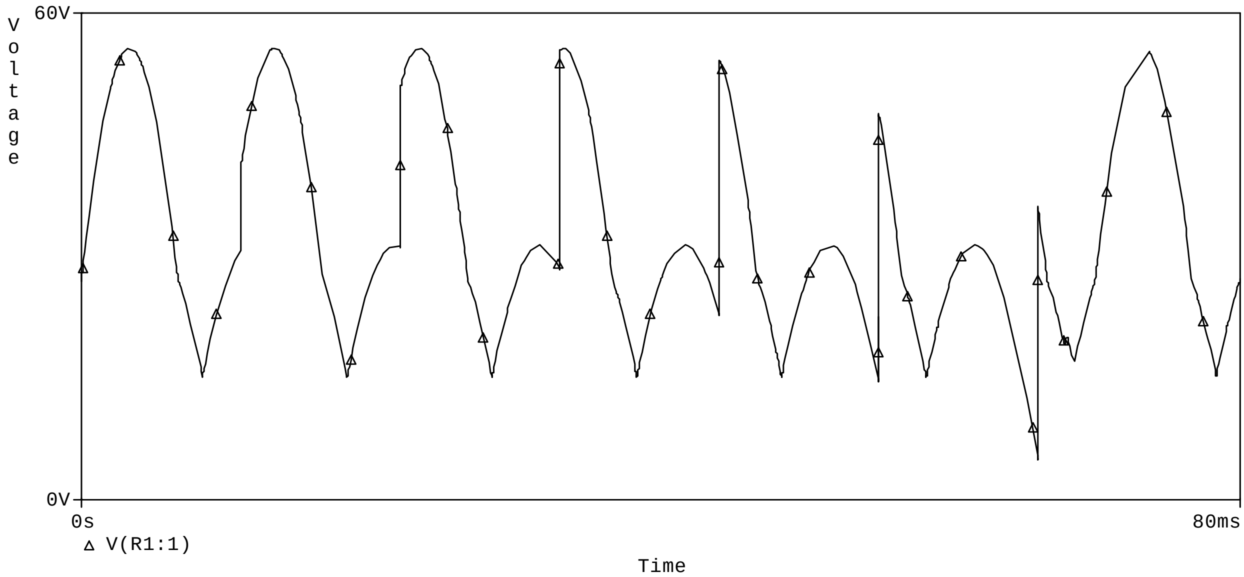

Figure 2 The output voltage waveform

FORMULATION OF Vd

1. For α= $0 \le \alpha < 30$ rectifier is in the nonsensitive zone as in this zone phase voltage $|V_B|$ is always higher than line voltage $|V_{AB}|$ even if the thyristors are fired current prefers the path through D1, D4. For this interval

$$V_d = \frac{1}{\pi}\left[\int_0^{30} Sin\left(wt + \pi/6\right)dwt + \sqrt{3}\int_{30}^{150} Sinwt\ dwt + \int_{150}^{180} Sin\left(wt - \pi/6\right)dwt\right]$$

2. For $30 < \alpha \le 60$ from the point where voltage $|V_B|$ crosses line voltage $|V_{AB}|$ up to point $|V_B|$ is maximum V_{AB} is higher than $|V_B|$ the thyristors operate and the current passes through the path T6 and D3. The thyristor T5 does not operate as negative voltage is applied to it for this duration. For this interval

$$V_d = \frac{1}{\pi}\left[\int_0^{60} Sin\left(wt+\pi/6\right)dwt + \sqrt{3}\int_{60}^{150} Sinwt\ dwt + \int_{150}^{180} Sin\left(wt-\pi/6\right)dwt\right]$$

3. For $60 < \alpha \le 90$ the thyristors still operate and the current passes through the path T6 and D3. For this interval

$$V_d = \frac{1}{\pi}\left[\int_0^{90} Sin\left(wt+\pi/6\right)dwt + \sqrt{3}\int_{90}^{150} Sinwt\ dwt + \int_{150}^{180} Sin\left(wt-\pi/6\right)dwt\right]$$

4. For $90 < \alpha \le 120$ T5 and D2 starts to operate together from where voltage $|V_B|$ crosses voltage $|-V_A|$ up to point that $|-V_A|$ is maximum For this interval

$$V_d = \frac{1}{\pi}\left[\int_0^{120} Sin\left(wt+\pi/6\right)dwt + \sqrt{3}\int_{120}^{150} Sinwt\ dwt + \int_{150}^{180} Sin\left(wt-\pi/6\right)dwt\right]$$

5. For $120 < \alpha \le 150$ T5 and D2 operate together where voltage $|V_{AB}|$ crosses voltage $-|V_A|$ For this interval

$$V_d = \frac{1}{\pi}\left[\int_0^{150} Sin\left(wt+\pi/6\right)dwt + \int_{150}^{180} Sin\left(wt-\pi/6\right)dwt\right]$$

6. For $150 < \alpha < 180$ both phase voltages are operating. For this interval

$$V_d = \frac{1}{\pi}\left[\int_{150}^{180} Sin\left(wt-\pi/6\right)dwt\right]$$

7. α=180 both thyristors are blocked and only phase voltage $V_B$is present.

$$V_d = \frac{2}{\pi}V_{Bm}$$

Let us consider influence of firing angle α to the excitation coefficient and get the characteristic $V_d(\alpha)$ of the designed rectifier (converter).

After integration and transformation we get the characteristic of the rectifier.voltage excitation coefficient

$$K_\Phi = \frac{V_d(\alpha)}{V_d(\min)}$$

α	0	30	60	90	120	150	180
K_Φ	1.87>$\sqrt{3}$	1.868>$\sqrt{3}$	1.846>$\sqrt{3}$	1.766>$\sqrt{3}$	1.63	1.370	1

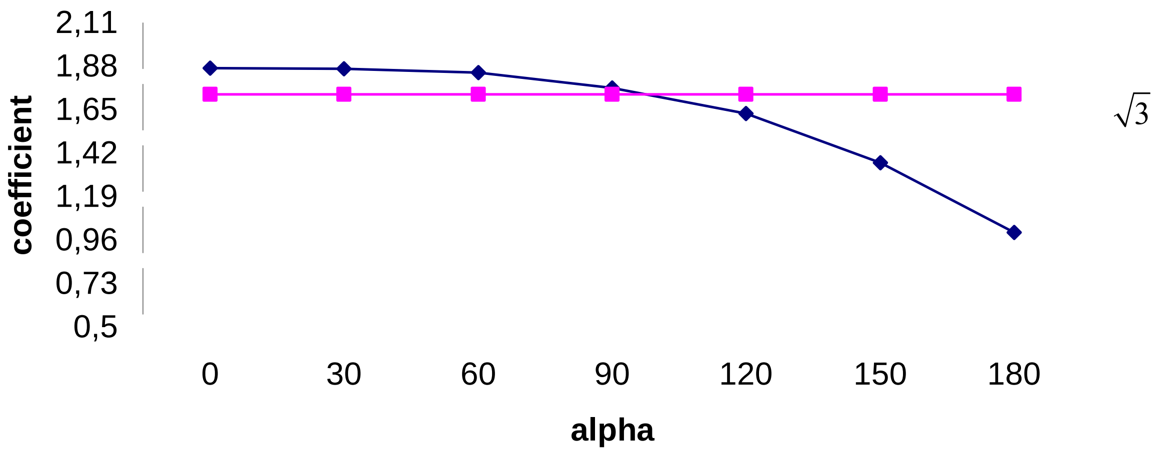

Table1 characterize the dependence of rectified voltage and K_Φ from angle α. Let us find the fourier series transform of the rectified voltage

In general $V_d(\alpha) = V_{d_0} + \sum_{n=1}^{\infty} A_n Cos\ nwt + \sum_{n=1}^{\infty} B_n Sin\ nwt$

Harmonic Analysis:

$$V_d(\alpha) = V_{d_0} + \sum_{n=1}^{\infty} A_n \cos n\omega t + \sum_{n=1}^{\infty} B_n \sin n\omega t$$

The harmonic coefficients are:

$$A_n = \frac{2}{\pi}\int_0^{\pi} V_d(t)\cos n\omega t\ d\omega t$$

$$B_n = \frac{2}{\pi}\int_0^{\pi} V_d(t)\sin n\omega t\ d\omega t$$

for the interval $0 \le \alpha \le 120^\circ$

$$A_n = \frac{2}{\pi}V_\phi \left\{ \begin{aligned} &\frac{\sqrt{3}}{2(1-4n^2)} + \frac{1}{1-4n^2}\cos\frac{5\pi n}{3} - \frac{1}{2(1+2n)}\cos\left[(1+2n)\left(\frac{\pi}{6}+\alpha\right)+\frac{5}{6}\pi\right] - \\ &\frac{1}{2(1-2n)}\cos\left[(1-2n)\left(\frac{\pi}{6}+\alpha\right)+\frac{5}{6}\pi\right] + \frac{1}{2(1+2n)}\cos\left[\pi\left(\frac{11}{6}+2n\right)\right] + \\ &\frac{1}{2(1-2n)}\cos\left[\pi\frac{11}{6}-2n\right] \end{aligned} \right\}$$

$$B_n = \frac{2}{\pi}V_\phi \left\{ \begin{aligned} &-\frac{n}{(1-4n^2)} + \frac{1}{1-4n^2}\sin\frac{5\pi n}{3} - \frac{1}{2(1-2n)}\sin\left[(1-2n)\left(\frac{\pi}{6}+\alpha\right)+\frac{5}{6}\pi\right] - \\ &\frac{1}{2(1+2n)}\sin\left[(1+2n)\left(\frac{\pi}{6}+\alpha\right)+\frac{5}{6}\pi\right] - \frac{1}{2(1-2n)}\sin\left[\pi\left(\frac{11}{6}+2n\right)\right] + \\ &\frac{1}{2(1+2n)}\sin\left[\pi\frac{11}{6}+2n\right] \end{aligned} \right\}$$

for the interval $120 < \alpha \le 180^\circ$

$$A_n = \frac{2}{\pi}V_\phi \left\{ \begin{aligned} &\frac{\sqrt{3}}{2\left(1-4n^2\right)} + \frac{1}{1-4n^2}\cos\frac{5\pi n}{3} - \frac{1}{2\left(1+2n\right)}\cos\left[\left(1+2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{\pi}{6}\right] + \\ &\frac{1}{2\left(1-2n\right)}\cos\left[\left(1-2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{\pi}{6}\right] + \frac{1}{2\left(1+2n\right)}\cos\left[\left(1+2n\right)\pi+\frac{5\pi}{6}\right] + \\ &\frac{1}{2\left(1-2n\right)}\cos\left[\left(1-2n\right)\pi+\frac{5\pi}{6}\right] - \frac{1}{2\left(1-2n\right)}\cos\left[\left(1+2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{5\pi}{6}\right] - \\ &\frac{1}{2\left(1-2n\right)}\cos\left[\left(1-2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{5\pi}{6}\right] \end{aligned} \right\}$$

$$B_n = \frac{2}{\pi}V_\phi \left\{ \begin{aligned} &\frac{n}{\left(1-4n^2\right)} + \frac{2}{1-4n^2}\sin\frac{5\pi n}{3} + \frac{1}{2\left(1+2n\right)}\sin\left[\left(1+2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{\pi}{6}\right] - \\ &\frac{1}{2\left(1-2n\right)}\sin\left[\left(1-2n\right)\pi+\frac{5\pi}{3}\right] + \frac{1}{2\left(1-2n\right)}\sin\left[\left(1-2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{5\pi}{6}\right] - \\ &\frac{1}{2\left(1+2n\right)}\cos\left[\left(1+2n\right)\left(\frac{\pi}{6}+\alpha\right)+\frac{5\pi}{6}\right] \end{aligned} \right\}$$

CONCLUSION

The designed and analyzed converter is simple to construct, cheap, and low distortion converter It is suitable for smooth up to ±15% exciting voltage control. The advantage over three phase traditional control rectifier is the possibility of better zone control. of Synchronous motors and generators.

The proposed low distortion rectifier can be implemented in common electrical applications such as: chemical electrolysis in the industry, DC motors , battery chargers etc.

This system helps to raise the stability of the synchronous machine, specially wind and subsea generating machine where naturally torque on the axe is unstable and various from time to time even abruptly.

For this system quick instantaneous rise (or fall down) excitation current can help to keep dynamic stability of the synchronous machine.

References

[1] P.G.Alizade et.al. Astudy of Thyristor exciting system of oil pump synchronous motor . Energy and Electrotechnique,No: 4 Scientific Reports,of Azerbaijan oil and Chemistry Institution.1974