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Modelling and Comparative Performance Analysis of Special Six-phase and Conventional Synchronous Generators for Wind Farm Application

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Six-phase synchronous machines have been studied for many years. In the late 1920's it was reported that these devices were used for a specific application where a phase shifting of 60º was required between two three-phase supply arrangements. Pursuing the goal of applying these generators in systems containing rectifiers, the technique of building up special generators has been found attractive in the sense of increasing the number of pulses. Although the mentioned references deal with the focused special machine, it must be stressed they are not strictly tight to wind system application. As a matter of fact, the subject of using six-phase generators with a 30° displacement between the two internal three-phase systems, as necessary for wind systems, is still a topic with a great lack of information as far as publications are concerned. On the other hand, it is worldwide known that the use of special six-phase generators has been pointed out as a modern tendency for new plants involving the exploitation of wind energy.

Therefore, the main goal of this work is the characterization of the special machine under discussion. The main topics described in this paper are related to the machine mathematical modelling throughout time domain representation, computational implementation into an appropriate program and performance analysis investigation in order to emphasise the special machine behaviour and its advantages in comparison to the classical three-phase generator.

The six-phase synchronous generator is built in such a way to provide two sets of three-phase windings (with displaced coils of 120º between). These two arrangements are displaced by an angle of 30º. Its structure presents two sets of three-phase windings, identified as *abc* and *xyz*, respectively. Fig. 1 evidences the constructive principle of the machine under analysis. The figure also shows the reference axes *abc*, *xyz* and the well known *dq* reference.

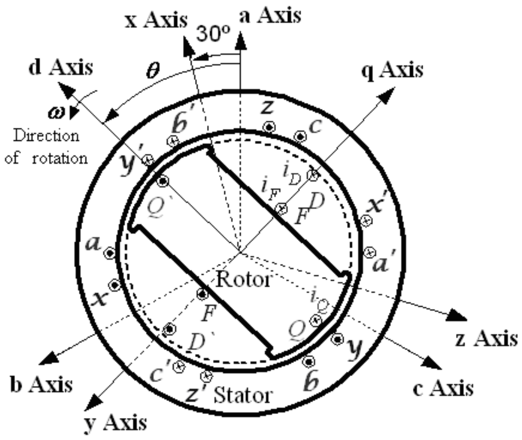

Fig. 1. Physical arrangement for the six-phase generator.

To obtain the representative expressions for the machine, the first step consists in finding the equations for the inductances. These must take into account the magnetic coupling between each pair of windings and that they dependent on the rotor position for salient pole machines. Once the inductances are known it is then possible to derive the electrical equation establishing the relationship between voltages and currents. In the sequence, it is possible to obtain the eletromechanical expression to associate the wind energy to the electrical one.

The above equations are fully described in the full paper in accordance with the time domain approach required by the chosen simulator.

The computational studies are associated to the simplified arrangement illustrated in Figures 2 and 3. The physical structure has omitted the downstream units of the rectifier which have been modelled by an equivalent constant resistive load. This makes the waveforms more appropriate to the analysis as no inverter switching interference will be noticed in the results. It is shown that the adopted configuration related to the special generator supplies a 12 pulse rectifier whilst the classical generator is feeding a 6 pulse unit.

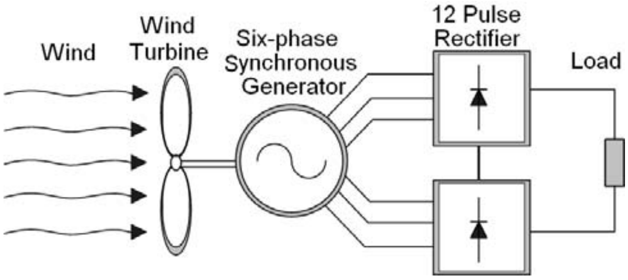

Fig. 2. Simplified system with six-phase generator and 12 pulse rectifier.

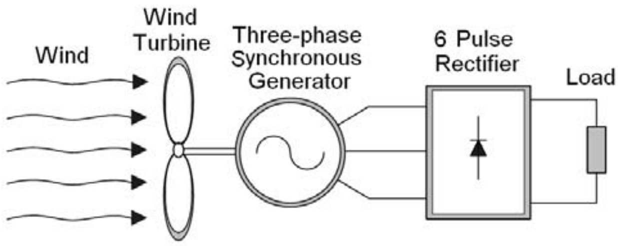

Fig. 3. Simplified system with three-phase generator and 6 pulse rectifier.

For both schemes the following operational variables are focused: three-phase voltages at the generator's terminals; three-phase currents supplying the rectifiers; magnetic flux in the machine; electromagnetic torque; field current; damper winding current; rectifier output voltage and current.

Regarding the primary source of energy, the winds, for both systems, are identical and show no turbulence. Due to difficulties associated with the necessary data to feed the developed model, the special generator parameters were taken from a conventional three-phase synchronous machine with the same rated power and voltage. These are to be given in details in the complete paper.

Just to provide a first view of the results, the Table I synthesizes and compare some operational characteristics for both generators. By looking at the harmonic distortions, damper currents, DC voltage level, etc, it is possible to conclude about the superiority of electric complex that makes use of the special six-phase synchronous generation.

In this abstract, Fig. 4 highlights the damper winding currents for the six-phase and three-phase machine. It can be noted that the six-phase generation unit produces a lower current in these windings. This can be taken into account as a first advantage for the machine.

TABLE I. - Comparative Performance Analysis for Both Generators.

Operational Variables	**Six-phase Generator**		**Three-phase Generator**	
	RMS value	Total Harmonic Distortion [%]	*RMS* value	Total Harmonic Distortion [%]
Line voltage (V)	582	5.6	586	8.4
Line current (A)	125	25	256	25
Magnetic flux (Wb)	2.6	0.62	2.7	1.1
Torque (N.m)	91502	13.5	91651	33
Field current (A)	183	28	186	68
Direct axis damper current (A)	275	28	643	35
Rectified voltage (V)	1564	3.1	784	7.7
Rectified current (A)	155	2.9	313	7.3

In fact, with an ideal operational condition with no waveform distortions, damper winding current should be null. Due to the non sinusoidal characteristics involved in the process, such a situation does not occur. Moreover, the six-phase arrangement gives a reduction of about 60% in the damper winding current RMS value and this, in its turn, will reduce heating problems under steady state conditions. The full paper is to give a few additional waveforms related to other electrical and mechanical variables.

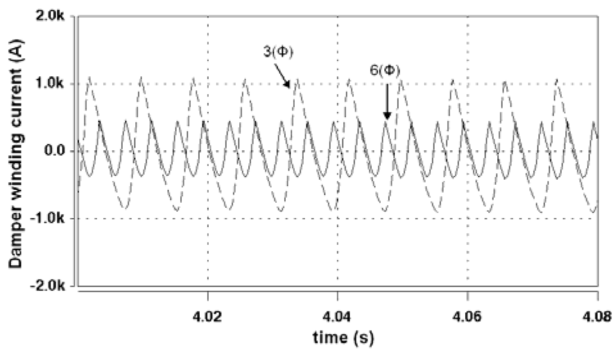

Fig. 4. Damper winding currents.

This abstract has shown that the paper gives a comprehensive model to tackle the time domain representation of special six-phase generators and their performance analysis. Throughout comparative computational investigation, the advantages of using the special machine for wind farm application are highlighted.