Three-Phase Synchronous Generators

Series DRA..., DRK...

Preface

Decades of experience in the manufacture of electrical machines and their use in industry, combined with the latest know-how in

- electromagnetic and mechanical design
- modern insulation technologies and ventilation
- the use of digital regulation
- rational manufacturing methods

are incorporated into the full range of products from VEM, especially the new series of three-phase high-voltage compact generators. This generation of synchronous generators is distinguished by its robust and simple design.

The compact construction is made possible by electromagnetic and design optimisation of the main components.

For the first time, a digital regulator has been used for these generators, offering maximum operator friendliness and ease of monitoring.
The digital voltage regulation ensures high voltage accuracy and excellent dynamic performance.
The essential operating parameters can be set conveniently by connection to a PC.

Three-phase high-voltage compact generators are mainly used with steam or gas turbines in industrial power stations. They are also used as diesel generators for continuous and standby power generation, as hydroelectric and marine generators, as well as for rotary converter sets.

Sachsenwerk offers you the ideal solution with customised and competitive machines for every use. They are distinguished by reliability, service friendliness, adaptability, modular construction, high performance and low noise parameters.

All our three-phase synchronous compact generators are tailored to specific customer requirements.

This catalogue contains general technical information. More specific enquiries need to be dealt with individually. Further technical data are available upon request.

Please feel free to contact our Sales Department or the VEM Sales Offices and Agents. Orders may be regarded as binding only after our written confirmation.

Delivery range

The high-voltage compact synchronous generator series with salient pole rotor is available in frame sizes 450 mm to 710 mm with 4-12 poles.

Rated power kVA
Number of poles

Synchronous generator series DRA ..., DRK ...

Standard design

Voltage:	6 kV and 10.5 kV
Frequency:	50 Hz
Thermal class:	F (used F)
Degree of protection:	IP 23 (open-circuit air-cooled)
Type of construction:	IM B3 (IM 1001)
Power factor cos φ:	0.8, over-excited

with digital exciter-regulator

Types of construction

The brushless synchronous generators supplied in the following preferred construction types

- IM B3 (IM 1001)
- IM B20 (IM 1101)
- IM B5/B20
- IM B16 (IM 1305)
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Protection and cooling methods

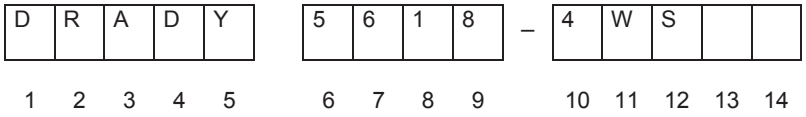
Degree of protection	IP 23
Cooling method	IC 01 open-circuit cooling IC 0 A1
Degree of protection	IP 44
Cooling method	ICW 37 A 81 air-to-water cooling IC 8 A1 W7

Machines with higher rated powers, different voltages and 60 Hz design are also available.

Type designation

The Sachsenwerk type designation consists of letters and numbers.

Letters	position 1-5
Numbers	position 6-9
Numbers	position 10-11
Letters	position 12-13



Type of current
D three-phase a.c.
Machine type
G synchronous generator with slip rings
R synchronous generator without sliprings
Cooling method, degree of protection
A self-ventilation IP 23/24
K closed-circuit cooling IP 44, IP 54 upon request
Version
(encoded information)
Application or bearing arrangement, non-standard voltage or frequency, explosion protection type, construction type, etc.
Frame size
(encoded information)
Core length
(encoded information)
Number of poles

Additional letters for modifications and special requirements
Code letters for specific winding types, pole types.

Standards and codes

The generators comply with the latest editions of the relevant DIN standards and DIN VDE regulations. For the standard machine configurations these are, in particular,
DIN VDE 60 034 (VDE 0530) and IEC 34 with the following parts:

Part 1	Rating and performance DIN EN 60 034-1 (VDE 0530-1) - IEC 34-1
Part 2	Methods for determining losses and efficiency DIN 57 530-2 (VDE 0530-2) - IEC 34-2
Part 4	Methods for determining synchronous machine quantities from tests DIN VDE 0530-4 (IEC 34-4)
Part 5	Classification of degrees of protection by enclosures for rotating machinery DIN VDE 0530-5 (EN 60 035-5) - IEC 34-5
Part 6	Methods of cooling DIN EN 60 034-6 (VDE 0530-6) - IEC 34-6
Part 7	Classification of types of construction and mounting arrangements DIN EN 60 034-7 (VDE 0530-7) - IEC 34-7
Part 8	Terminal markings and direction of rotation DIN VDE 0530-8 - (IEC 34-8)

Part 9	Noise limits DIN EN 60 034-9 (VDE 0530-9) - IEC 34-9
Part 14	Mechanical vibrations... DIN VDE 0530-14 (VDE 0530-14) - IEC 34-14
Part 15	Impulse voltage withstand levels... DIN EN 60 034-15 (VDE 0530-15) - IEC 34-15
Part 16	Excitation system for synchronous machines DIN EN 60034-16...(VDE 0530-16) - IEC 34-16..
Part 18	Functional evaluation of insulation systems DIN EN 60 034-18-1 (VDE 0530-18-1) - IEC 34-18...

and

DIN ISO 8821	Mechanical vibration; Balancing; shaft and fitment key convention
DIN ISO 7919-...	Mechanical vibration of non-reciprocating machines - Measurements on rotating shafts and evaluation criteria
DIN ISO 10816-...	Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts

For explosion-protected machines the following standards are also applicable:

DIN VDE 0165	Installation of electrical apparatus in hazardous areas
DIN VDE 0166	Electrical installations and apparatus thereof for use in atmospheres potentially endangered by explosive material
DIN EN 50 014 (VDE 0170/0171 P. 1)	Electrical apparatus for potentially explosive atmospheres; General requirements
DIN EN 50 016 (VDE 0170/0171 P. 3)	Electrical apparatus for potentially explosive atmospheres; Electrical apparatus for potentially explosive atmospheres;
DIN EN 50 019 (VDE 0170/0171 P. 6)	pressurised apparatus "p2 Electrical apparatus for potentially explosive atmospheres; increased safety "e".

Upon request, the generators can also be supplied to other standards and specific industrial regulations, such as ZLM (Additional Terms of Supply for High-Voltage Electric Motors in Power Stations) and to the specifications of all major classification societies.

Mechanical design

The three-phase synchronous generators comprise the main generator with salient pole rotor, stationary-pole exciter and excitation system.
The rotating diode bridge to rectify the three-phase current of the exciter is mounted on the NDE shaft end. It is easily accessible through a service opening, in case the diodes need to be exchanged.
The exciter rotor and the diode bridge are mounted on a common bushing forming an integral unit.
The digital voltage regulator used as standard is mounted on the generator terminal box at the N-end.

Stator

The stator is a single-piece welded construction resting on four foot plates. The laminated core consists of insulated circular electrical steel laminations. It is secured axially by bars welded to the back.

Rotor

The laminated rotor of the main generator is a directly wound salient pole rotor with the exciter rotor and the rotating rectifier bridge shrunk onto the same shaft.
All rotors are dimensioned for operation at 60 Hz. The rotor core is clamped by clamping plates installed on the shaft.

Stator winding

The three-phase stator winding is embedded in the open slots of the core. It is designed as a chorded double-layer integral coil winding. The conductor material is copper strips insulated with mica-glass-epoxy resin tapes. The coil connectors are brazed. The end windings are reliably supported by ties and spacers to withstand the mechanical stress occurring during switching operations.

The complete stator winding is vacuum-pressure-impregnated with epoxy resin. The coils are locked in the slots by fibre glass-epoxy resin slot closers.
For corona shielding, a low-resistance protective coat is applied on the bars in the slot portion and a high-resistance coat at the slot ends.

Rotor winding

The exciter coils are made of varnish-glass insulated copper strips wound directly on the integrally stamped poles. The voids are filled by the vacuum pressure impregnation. The tangential centrifugal forces are taken up by supports in the pole gaps. The coil connectors and the connections to the diode bridge are also supported.

The damper winding consists of round copper bars which are evenly distributed over the pole surfaces and welded to the steel clamping plates of the laminated core.

Bearings

The brush-less synchronous generators are equipped with anti-friction bearings as standard. Sleeve bearings can be provided against extra charge upon request by the customer.

When anti-friction bearings are fitted, a locating bearing is used at the D-end and a non-locating bearing at the N-end. The bearing heads are flanged to the end shields.
If sleeve bearings are used to carry the rotor, they are designed as non-locating bearings and similarly flanged to the end shields.

If properly maintained, the bearing life is practically unlimited.

Both the D-end and N-end bearings can be insulated from the end shields.

Depending on the frame size and speed, lubrication is either oil ring lubrication or flood lubrication (forced-oil lubrication).
If two non-locating bearings are fitted, axial location must be ensured by the drive motor by way of a limited-end-float coupling.

Terminal connection

The terminal boxes are either IP 54 or IP 55.
The terminal leads can be connected to the terminal box either from the N-end, from the right side or from the left side.

Using cast resin bushing insulators and ample-sized studs, the terminal boxes are mechanically short-circuit proof.

An initial symmetrical short-circuit of 40 kA is withstood for 0,2 s, which is equivalent to a short circuit power of

440 MVA at 6.3 kV or
730 MVA at 10.5 kV

Large-size relief diaphragms make the terminal boxes short-circuit-proof. If a short-circuit occurs within the terminal box, the pressure is diverted towards the generator to prevent possible injury to the personnel.

The neutral point is connected via 3 current transformers.
Two V-connected potential transformers are provided for voltage regulation.

Monitoring devices

In order to prevent impermissible loads during operation, the generators are equipped with the following monitoring devices as agreed with the customer.

Location	Monitoring device
Stator winding	6 embedded RTDs Pt 100
Bearings	SPM nipple (1 RTD Pt 100 each 1 oil level gauge each with sleeve bearings)
Below coolers	1 leakage water detector (air-to-water cooler)

Cooling principle

In the standard version, the synchronous generators are open-circuit cooled (IC01).
The unidirectional fans are arranged at the D-end.
Generators with 4 to 8 poles are cooled axially.
Radial cooling is used for the 10 to 12-pole versions. The cooling air is drawn in at the N-end and blown out laterally.

In the enclosed version IP 44, the generators are supplied with top-mounted air-to-water heat exchangers. The electrical design and power assignment remain unchanged from those of the standard design.

Regulation

Excitation system with digital regulator

The brush-less excitation system comprising three-phase exciter, rotating rectifier bridge and varistor for over-voltage limitation is designed on proven principles.
Being over-dimensioned, the system controls all operating points within the stable range of the generator capability curve as well as overloads, and thus meets all standard dynamic requirements are met.

The excitation is controlled and regulated by a specially developed digital regulator
ensuring the following basic functions:

- Voltage regulation (± 0.5 %)
- Remote reference value adjustment by external contacts
- Reactive power droop
- Frequency-dependent voltage reduction
- Excitation voltage limitation
- Automatic excitation build-up through remanence
- Automatic de-excitation when shutting down the generator
- High-speed de-excitation
- Signalling of excitation faults
- Interface for p and d

Optionally, the following functions can be provided:

- Generator current limitation
- Reactive power or cos φ regulation
- Reactive power setting internally or externally
- Reactive power limitation
- Mode change-over by external contacts
- Signalling of rotating diode defects

It must be mentioned in this connection that both the excitation current and generator current limitation are based on a time-dependent limit value. This takes both the dynamics and the permissible generator temperature rise into account.

The digital regulator is mounted on the generator terminal box at the N-end, the generator and the regulator forming a single functional unit. The electrical connection is by a plug-and-socket connector.

A separate interface for parametrisation and diagnosis is provided on the regulator housing side, permitting parametrisation and diagnosis to be performed during any operating state of the unit. An appropriate device can be supplied for this purpose.

An optional laptop with complete software for regulator visualisation is being prepared.

In this way, the regulator can be parametrised, diagnosed or replaced both quickly and easily, if required.

The connection to the control room is made on the terminal strip in the generator auxiliary terminal box.

Furthermore, the digital regulator can be extended to include the following functions without any mechanical changes being required.

- Excitation build-up from battery
- Load angle limitation
- Line compensation
- Connection to superior control system (CAN bus)

- Rotor earth fault detection, brushless
- Power stabilisation, switchable

It should, however, be added that user opinions differ on the necessity of the power stabilisation function.

Electrical design

Rated power

In the standard version (catalogue data), the synchronous generators are designed for a rated frequency of 50 Hz, rated voltage ± 5%, cos φ = 0.8 over-excited, internal air temperature ≤ 40°C, altitude < 1000 m a.s.l. and a temperature rise in accordance with thermal class F.

If air-to-water heat exchangers are used, a water inlet temperature of ≤ 27° C is required.

With degree of protection IP 44 and air-to-water heat exchanger, the output power is independent of the ambient temperature. It is only dependent on the altitude, cooling water flow and the water inlet temperature.

Differing output power assignment

The permissible output power for differing rated values of power factor, coolant temperature and altitude is a matter of consultation with VEM.

In the case of other influencing factors which could require a differing output power assignment such as

- air filter
- operation at unbalanced load
- harmonic load
- temperature rise class B
- dynamic voltage change upon connection to line

consultation with VEM is necessary.

Brushless excitation system

A uniform excitation principle is used over the whole power range. Being powered from an auxiliary winding, the excitation unit is independent of the voltage level of the main generator.

The excitation power for the rotor winding of the main generator is provided by a three-phase stationary-pole exciter which is installed at the N-end.
The field winding of the exciter is powered from the auxiliary winding installed in several slots on the main generator.

The excitation system is amply dimensioned for all operating states and for the continuous short-circuit current. The rectified auxiliary winding voltage is fed to a transistor chopper. The regulator and chopper ensure that the appropriate excitation current is provided for the exciter for the different load levels.

Characteristics and performance

Voltage and frequency

Generators with the standard configuration are designed for rated voltages of 6.3 kV and 10.5 kV at a rated frequency of 50 Hz. The setting range of the reference adjuster is
± 5% reference voltage and can be extended to ± 10%. Differing rated voltages are available upon request.

Mechanically, the generators are dimensioned so that operation at 60 Hz is possible, with the rated power increasing by about 20% compared to the power listed for 50 Hz.

Voltage curve shape

An appropriate winding design results in a practically sinus-shaped line-to-line no-load voltage.
The telephone harmonic factor (THF) is below the values specified in VDE 0530.
$P_S \leq 5{,}000$ kVA - t.h.f. ≤ 3%.

Stator winding connection

The stator winding is star-connected. The neutral is formed inside the machine and is brought out to a fourth terminal. If differential protection is provided, an open neutral
(6 terminals) is possible.

Overload capability

The generators are designed to operate for 120 s at 1.5 x rated current.

Considering the overload capability of combustion engines, the generators can be operated at 110% rated current for one hour within six.

The excitation system is amply dimensioned for dynamic processes, i.e. about 230% ceiling voltage is available.

Short-circuit performance

Sudden short-circuit current

The sudden short-circuit current is far below the value $I_S < 15 \times I_N$ laid down in VDE 0530.

Sustained short-circuit current

The generator auxiliary winding and the excitation winding are designed so that in case of a three-phase short-circuit at the terminals a continuous short-circuit current of about $3 \times I_N$ is withstood for $t < 5s$.

Unbalanced load

The generously dimensioned damper cage permits unbalanced loads.
The generators dimensioned for continuous unbalanced load (negative-sequence current/rated current ratio) of $I_2/I_N < 20$ %.
Optimum operation, however, is obtained with symmetrical loads.

Dynamic voltage behaviour

Sudden load changes result in voltage changes ΔU which are mainly determined by the transient generator parameters and the external system connection conditions such as

- load connected
- cos φ during connection to system
- generator at no load or generator preloaded.

When connecting loads of approx. I_N and cos $\varphi < 0.4$ transient voltage dips of ΔU 15-25% are to be expected.

The transient response of the generator voltage is determined by the time constants of the main generator, the exciter and the regulation system.

The amply dimensioned excitation system ensures short recovery times.

The recovery time for transient voltage variations is about 600 ms, depending on the number of poles and the generator output. After about 300 ms, the voltage tolerance range is reached temporarily and, following correction, the specified static voltage tolerance range is then maintained.

Classification of ships

The individual classification rules and regulations demand lower generator temperature rises for on-board use and thus require a corresponding derating (see table).

Overload requirements / permissible temperature rise

Classification rules	Coolant temp. °C	Permissible stator winding temperature rise thermal class F (K)	Overload and period	S/S_N
VDE 0350	40 (105)*	100	50% 30 s	1.0
Germanischer Lloyd	45	95	50% 2 min	0.95
Bureau Veritas	50	90	50% 2 min	0.925
Det Norske Veritas	45	90	50% 2 min	0.925
Lloyd's Register of Shipping	45	90	50% 15 s	0.95
RINA	50	90	50% 2 min	0.925
American Bureau of Shipping	50	90	-	0.925

)* Generators < 5,000 kVA

Universal VEMoDUR insulation system

The operational reliability of electrical machines is influenced decisively by the quality of their insulation systems. Sachsenwerk's insulation systems are and have always been technical solutions with quality parameters meeting all international standards, thus guaranteeing the user products of high dependability and with a long service life.

Our high-voltage machines of all power ranges are insulated using the vacuum pressure impregnation process (VPI). The corresponding insulation system VEMoDUR-VPI-155 was developed by Sachsenwerk and is registered as a trade mark under the name of VEMoDUR, with VEM standing for "Vereinigter Elektromaschinenbau" and "DUR" characterising the thermosetting properties ("Duroplast") of the insulation system with synthetic binders.

This system uses the following main components for stator windings:

Turn insulation	⇒	mica film tapes
Main insulation (slots and end windings)	⇒	low-binder mica-glass-silk tapes (containing accelerator)
Impregnating resin	⇒	epoxy resin

The components are optimally adapted to each other. Thermal class F has been verified by many years of experience in the operation of generators with this insulation system and by functional evaluations according to IEC 34-18-31.

To ensure the quality of the insulation system, all components are subjected to an incoming goods inspection in accordance with DIN ISO 9001.

During the impregnation process the insulation is subject to constant checks, with recording of the relevant characteristics, such as:

- Viscosity of the resin
- Component and resin temperature
- Vacuum holding time
- Pressure holding time
- Pressure level
- Through-impregnation
- Curing temperature and time

The vacuum-pressure impregnation ensures high mechanical strength (stiffness of the end windings) and an outstanding electric strength. This applies especially to impulse withstand voltage levels. The rated impulse voltages specified in DIN VDE 0530 P.15 (IEC 34-15) are reliably guaranteed for all VEM machines (see Table below).

The insulation system is characterised especially by its climate-proofness, i. e. it is highly resistant to moist or aggressive atmospheres.
:

Rated impulse voltages for rotating electrical machines

Rated voltage	Rated lightning impulse voltage (peak value)	Rated impulse voltage with extremely short front time	Mains frequency test voltage (rms value) to IEC 34-12
U_N (kV)	U_P (kV)	U_P (kV)	U_N+1 (kV)
3	17	11	7
3.3	18	12	7.6
4	21	14	9
6	29	19	13
6.6	31	20	14.2
10	45	29	21
11	49	32	23
13.2	58	38	27.4
13.8	60	39	28.6
15	65	42	31

This insulation system described here is the standard version.
Sachsenwerk is also able to supply special versions for higher rated impulse voltages upon customer request.

Example: U_N = 11 kV
Main insulation: 80 kV
Turn insulation: 60 kV

The insulation is subjected to intermediate and final tests of the insulation resistance, including discharge and partial discharge tests, within the framework of internal quality inspections and tests according to DIN VDE. This ensures the competitive and high quality of our insulation systems.
Upon customer request, these test steps can be agreed and carried out separately.

The VEMoDUR insulation system is also suitable for EExe machines (increased safety) according to DIN EN 50019.

Quality assurance

An efficient quality system guarantees the optimum quality of our synchronous generators.
All generators undergo stringent final testing. The results are documented in the relevant test reports.

Series and routine tests performed on all generators

- Visual inspection (marking, completeness)
- Loss tangent test on installed stator winding
- Insulation resistances of windings, temperature sensors, space heaters, bearings
- DC resistances of windings, temperature sensors, space heaters
- Adjustment of magnetic centre of generators with sleeve bearings
- Measurement of rotor impedance
- Phase-sequence test
- Vibration severity measurement
- Check of voltage balance
- No-load characteristic, generator mode
- Short-circuit characteristic, generator mode
- Shaft voltage measurement (where design permits)
- Shock pulse measurement, if SPM nipple is provided
- High-voltage test
- Functional check of accessories
- Functional check of excitation system.

Additional tests / type tests

Type tests are performed on one generator as a representative of the type, with the scope of testing depending on our technical capacities. The test is included in the generator price. Upon request, additional tests can be performed at extra charge to the customer.

- Overspeed test with generator on balancing machine
- No-load characteristic
- Determination of iron and friction loss
- Noise measurement at no-load
- Measurement of THF factor
- Moment of inertia in deceleration test
- Sudden short-circuit test
- Temperature rise test at rated data or equivalent load test
- Temperature rise time constants
- Load characteristics $\eta = f(P_{el})$
- Regulation characteristics for different cos φ
- Determination of nominal excitation current
- Determinations of synchronous machine characteristics (reactances, time constants)
- Measurement of coolant flow rate

Documentation

The scope of the Operating and Maintenance Manual is agreed with the customer on the basis of the General Terms of Delivery for Products of the Electrical Industry.
The standard version of the manual comprises:

- Data sheet
- Test report
- Dimension drawing of generator
- Dimension drawing of cable connection
- Connection diagrams
- Erection instructions
- Subsupplier documentation
- Spare parts list
- Manufacturer’s declaration (CE)

Should a more comprehensive documentation be required, especially for export contracts, then this is to be agreed separately between the purchaser and VEM.
The 2 sets of documentation are furnished together with the machine. The documentation is available in German, English, French, Russian, Spanish and other languages.
Additional copies or an enlarged scope of documentation are available at extra charge.

Shipment, packing, erection

Subject to specific loading limits, the compact synchronous generators are shipped fully assembled wherever possible. The shaft of machines with sleeve bearings is blocked during transport. Generators with oil lubrication are supplied without oil filling. Care must therefore be taken before commissioning to ensure that the shipping bracket is removed and that the generator is filled with oil. The erection instructions should be observed closely to ensure proper installation of the machines.
Erection of the generators can also be carried out by Sachsenwerk specialists. Mounting or anchoring parts, such as foundation bolts, etc., can be supplied to special order.
The type of packing is determined at the time of conclusion of the contract, depending on the transport and storage conditions stated in the purchase order and taking into consideration the design and construction of the machines. Sachsenwerk is able to offer all types of special packing, thus ensuring that generators can be erected in even the most distant places.