

Static frequency converter couples US paper mill's 25-Hz and 60-Hz electricity grids

Before 60 Hz was adopted as the standard frequency for electricity distribution in the USA, power companies across the nation had traditionally operated with a frequency of their own choice. In Pennsylvania, for example, 25 Hz was widely used, and even today there are a large number of power networks still operated as 25-Hz 'islands'. Only recently, as modern static frequency converters have come onto the market, has it become possible to exchange energy between these networks and the 60-Hz grid.

For historical reasons, *Westvaco Corporation's* paper mill in Tyrone, Pennsylvania, was originally operated with 25-Hz power. Since the nation-wide adoption of 60 Hz as the standard frequency for power distribution, the mill has shifted towards the use of 60-Hz power, and today only a 6-MVA steam turbine with a useful output of approximately 4 MVA at 25 Hz is left in the plant.

Conversion of all of the electrical equipment to 60 Hz at the same time was not a viable proposition. After considering all the options, the mill's management decided that the best solution was to install a frequency converter. This would export power to the plant's 60-Hz system, and the 25-Hz steam turboset could be operated at full power, which has advantages for the operation of the turbine [1]. Also, it would allow a black start of the 25-Hz side and be able to meet load demand

if and when the 25-Hz steam turboset is phased out or converted to 60 Hz.

Frequency converter characteristics

Consultations between ABB and Westvaco showed that a system with voltage-source converter modules based on GTO thyristors was the right solution for Westvaco's Tyrone mill.

The voltage-source converter with self-commutated GTO thyristors is fundamentally different to the current-source type with conventional thyristors.

Thyristor converters are line-commutated, meaning that power gener-

ation is needed on the AC side for the commutation of the thyristors. As a result, this technology is unsuitable for black starts and for power inversion, in which energy is fed back into a grid lacking its own generator or source of reactive power. The thyristor converter produces considerable harmonics and operates at varying power factors, depending on the actual firing angle. This makes the thyristor converter less suitable for use in grids with a low short-circuit rating, and large AC filters are often required to compensate for the harmonics and the low power factor.

The problems experienced with thyristor converters can be overcome by using a voltage-source converter. Since the GTO (gate turn-off) thyristors are self-commutating, generated power is not needed on the AC side for the thyristor commutation. Thus, the GTO thyristor converter is well suited for black starts and feeding power back into grids lacking other means of power generation.

Harmonics filtering on the AC side can be greatly reduced or even completely eliminated by combining the GTO converter with optimized transformer connections and switching patterns. Another benefit of self-commutation is that the voltage-source converter is able to operate at any power factor. The converter can therefore be tuned to the power factor best suited for the given system or combined with a voltage regulator which will automatically adjust the reactive power (VAr) output independently of the active power (watts). The voltage-source converter can even be operated as a static var compensator, if required.

System configuration

The frequency converter system **1** consists of eight 1,000-kVA power and capacitor bank modules **2** for a maxi-

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mum energy transfer of 4 MVA. Voltage and current measuring devices in the DC bus record the power being transferred. Measurements are also carried out by current and potential transformers in the 25-Hz and 60-Hz AC buses.

The converters are connected to two 60-Hz transformer pairs and two 25-Hz transformer pairs.

Although the new system's reliability is excellent, the configuration that was chosen has the additional benefit of offering redundancy. This has been achieved by interconnecting the DC bus between all four converter pairs. In the unlikely event of a component fail-

ing, the affected part of the frequency converter can be disconnected and operation continued at half-power.

Circuit-breakers

On the 25-Hz (4,160-V) side, an existing AC circuit-breaker connects the converter transformers to the grid 3. Potential and current transformers provided by Westvaco interface with the controls.

Two circuit-breakers, rated at 1,200 A, 5 kV and 60 Hz, were installed on the 60-Hz (2,400-V) side.

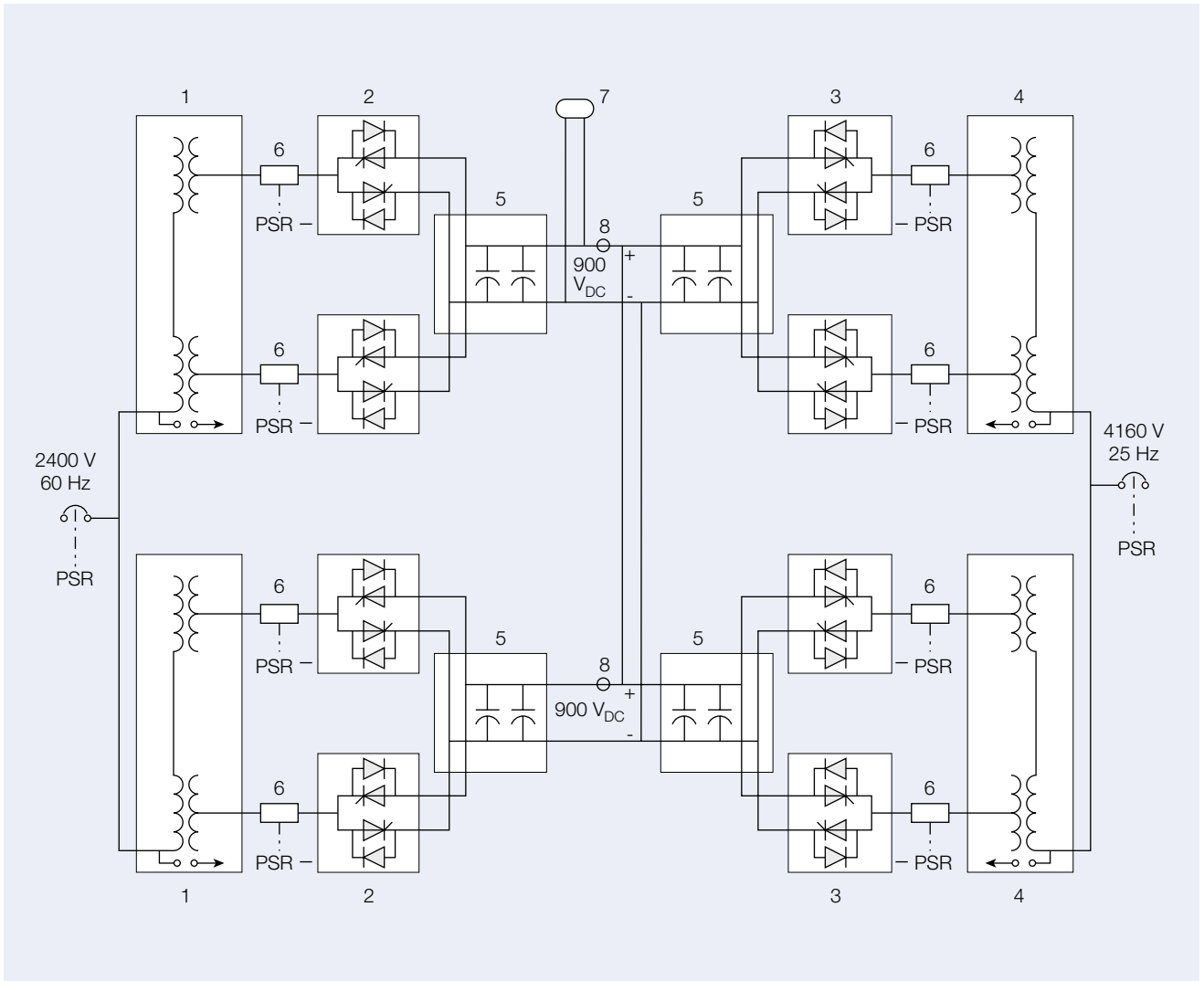
One of the breakers is located close

to the 60-Hz inverter transformers and interfaces with the controls via potential and current transformers. The other breaker, which is located in the 60-Hz switchyard, is equipped with a reverse current/power relay and a 50/51N over-current/ground fault relay as well as the same potential and current transformer as the other two circuit-breakers.

No other metering or relaying equipment is provided with the breakers, since all the necessary functions are performed by the frequency converter's controller and displayed locally on the operator's panel.

One half of the frequency converter, rated at 2 MVA, for Westvaco Corporation's paper mill in Tyrone. The cabinet with the controls is on the left.





Single-line diagram of the new frequency converter for the paper mill in Tyrone, where it will exchange power between the mill's 25-Hz and 60-Hz power systems

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- 1 Transformer pairs, 60 Hz
- 2 Inverters, 60 Hz
- 3 Inverters, 25 Hz
- 4 Transformer pairs, 25 Hz
- 5 Capacitor banks
- 6 Monitoring devices (used to prevent DC saturation of the transformers)

- 7 DC voltage measuring device
- 8 DC current measuring devices

PSR Programmable high-speed controller

Converter modules

A total of eight modified 1,000-kV SAMISTAR drive modules **4** are used in the installed converter system. SAMISTAR technology is economical and proven in the field, with thousands of modules in operation as motor drives in paper mills and rolling mills all over the world.

The converter control system is interfaced to each power module over six fiber optic cables with the help of a special interface card. These fiber optic links are used to transmit the switching pattern for each phase as well as the 'run', 'reset' and 'trip' signals.

Each power module features local protection covering the following situations:

- GTO thyristor failure
- GTO thyristor overcurrent
- Undervoltage and overvoltage on DC bus
- DC chopper undervoltage and overvoltage

- Auxiliary power failure
- Heat-sink overtemperature

The following functions are also handled locally:

- Minimum on- and off-times for the GTOs
- GTO current limitation

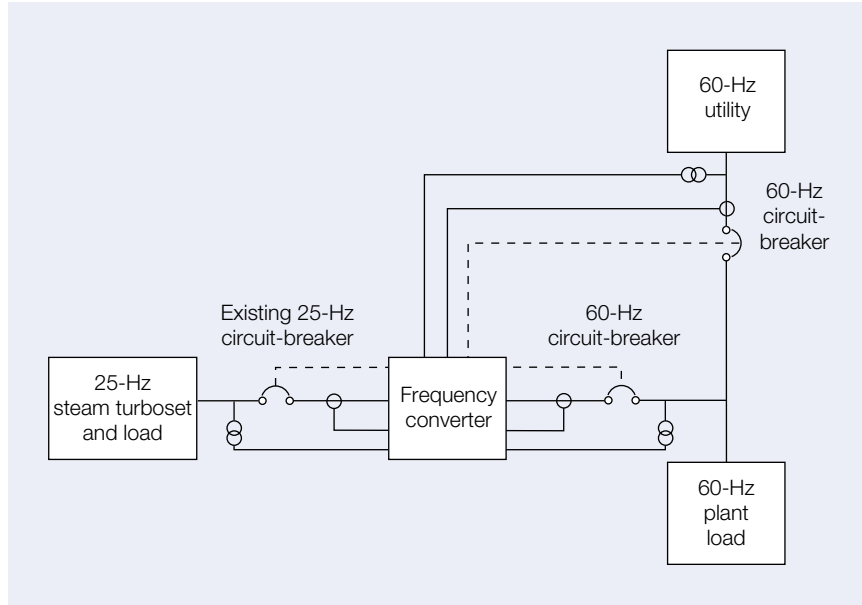
A special feature of the power module is that it is extremely compact. A 1,000-kVA air-cooled unit is 66.5" (169 cm) high, 21.7" (55 cm) wide and 21.3" (54 cm) deep, allowing it to fit nicely into a 33.5" (85 cm) wide cabinet. The corresponding capacitor units are 71.6" (182 cm) high, 8.5" (21.6 cm) wide and 19.7" (50 cm) deep, so that two units fit into a 23.5" (59.7 cm) wide cabinet.

Both the converter and the capacitor units are designed as modules, fitted with wheels and stand on rails in the cabinets to facilitate easy access for repairs and replacements.

The power modules are also remarkable for their very low losses. Innovative circuitry is used to recover the GTO snubber energy. A DC chopper feeds the snubber energy back to the intermediate DC circuit, thus contributing to a converter efficiency of better than 98 percent. This not only improves the operational balance but also greatly reduces the cooling requirements.

Transformers

The frequency converter works with eight dry-type transformers. Each transformer unit has a rating of 750 kVA and is cooled by natural air convection. With forced-air cooling, the rating rises to 1,000 kVA. 12- or 24-pulse transformer connections are required to minimize the harmonics generated by the frequency converter. Theoretically, there are more harmonics with a 12-pulse transformer connection than with a 24-pulse connection, but the difference is greatly reduced by ABB's optimized switching pattern. Other disadvantages of the 24-pulse configu-



Circuit-breaker arrangement for Westvaco's new static frequency converter system

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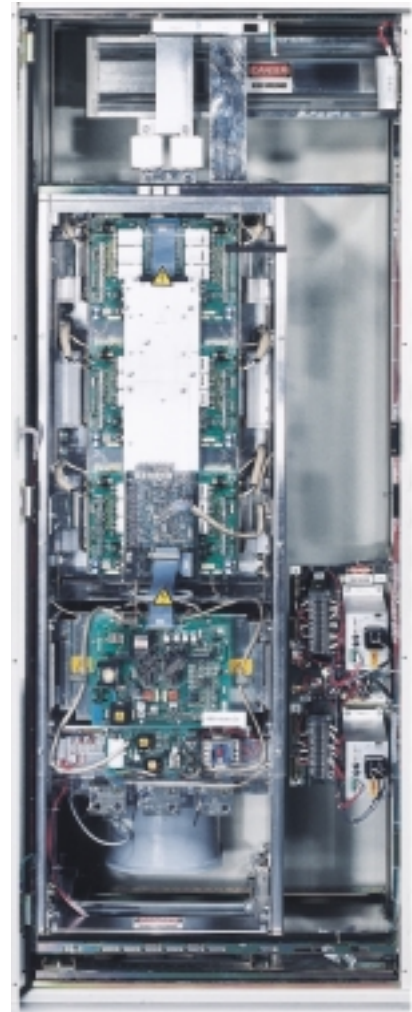
SAMISTAR AC drive module, with the motor control card replaced by an interface card for the PSR controller

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ation is that it requires special transformer windings and offers less redundancy than two 12-pulse systems.

In most cases, the combination of 12-pulse configuration and ABB's optimized switching pattern reduces the harmonics generated by the frequency converter to a level below the limits specified by IEEE STD 519 without additional AC filters. After due consideration had been given to all of these factors, preference was given to the 12-pulse transformer configuration 5.

It should be noted that the two transformers forming a 12-pulse connection are connected on the primary side in series rather in parallel. This is different to the transformer connection used for current-source converters (eg, thyristor or diode rectifiers), which normally have two transformers in parallel or one single transformer with two secondary windings.



Parallel secondary windings are not an option with voltage-source converters, since the switched voltage of each converter module will short circuit through the flux of the common transformer core. This problem is avoided by having two separate transformers. Serial connection of the primary transformer windings adds the converter voltages together, resulting in 12-pulse performance. Equal current sharing between the converters is also enhanced by the serial connection.

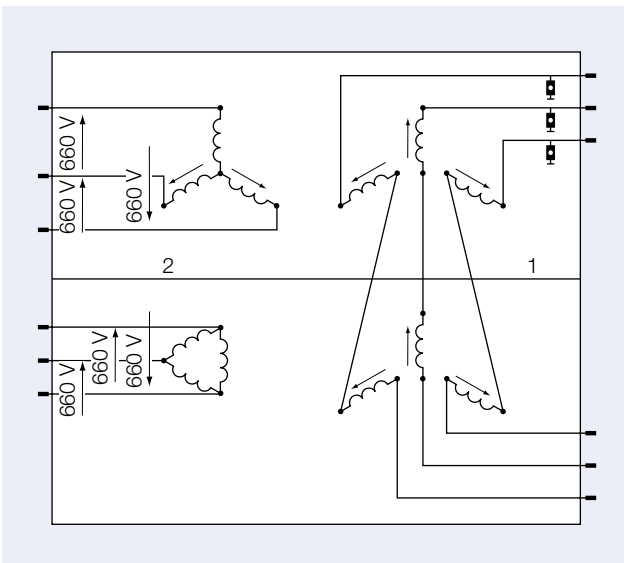
To avoid saturation of the transformers, it is important to ensure that the converters do not generate any DC voltage components at their AC terminals. DC components in the range of

Operator's panel with PSR high-speed controller 6



The 12-pulse transformer connection chosen for the Westvaco project 5

- 1 Primary side connected to the grid
- 2 Secondary side connected to the converters



10–300 mV may be generated unless preventive measures are taken. Given the low internal winding resistance and magnetizing currents of power transformers, such a DC voltage will cause a DC flux that will saturate the transformer. ABB has solved this problem by providing high-accuracy feedbacks in the

converter for active compensation of any DC components.

Controller

The frequency converter is controlled by a programmable high-speed controller called the PSR 6 [2]. This modular

system comprises a processor, analogue and binary I/Os, pulse-width modulators (PWMs) and an operator's panel, etc. The controller section can thereby be tailored to meet different system and customer requirements.

The PSR processor unit supports an Arc Net field bus system. This allows

the PSR, with the help of a serial protocol, to read the contact status inputs and to drive relays via a coaxial cable. It is also connected to the operator's interface, which is programmed to show all alarms, trips, currents, voltages, power setpoints, etc.

The 60-Hz converters have PWMs featuring a five-fold switching frequency, optimized for the 12-pulse configuration. This results in a GTO switching frequency of 300 Hz.

The 25-Hz converters have PWMs with an 11-fold switching frequency for a GTO switching frequency of 275 Hz.

Software

The software used for the PSR system is FUPLA 2, for Function Plan Language, version 2. Using this software, all the control functions can be programmed using mathematical and logical functionality blocks, such as adders, multipliers, etc. Sequential functions are programmed with ladder equivalent software.

The software is written to facilitate the following functions:

- Interfacing with the operator's panel. Read commands and setpoints. Display system variables, status, alarms and trips.
- All sequential controls. System start and stop.
- Synchronous sampling and reading of the 25-Hz and 60-Hz variables, plus synchronization with both systems via phase locked loops (PLL).
- The 60-Hz software controls the DC bus voltage, holding it at a nominal 900 VDC. The DC bus voltage controller provides the reference for the active current controllers.
- The reference for the 60-Hz reactive current controller is provided by a power factor or reactive power controller. The operator can select the setpoint and preferred operating mode for the latter controller. In

cases of high power flow, a current limiter gives the active current priority over the reactive current.

- When power is generated on the 25-Hz side, the frequency controller must be operating in current control mode on the 25-Hz side. The active 25-Hz current component is used to control the power flow through the frequency converter.
- The reference for the 25-Hz reactive current controller is provided by a power factor or reactive power controller. The operator can select the setpoint and the preferred operating mode for the reactive power controller. In cases of high power flow, a 25-Hz current limiter gives the active current priority over the reactive current.
- In cases where no power is generated on the 25-Hz side, an AC voltage controller is needed. The 25-Hz PLL is replaced by a fixed 25-Hz frequency reference. The voltage controller is set such that it maintains the 25-Hz line voltage at its nominal value. The current flowing into the 25-Hz grid will therefore be decided entirely by the actual 25-Hz load. A current limiting function is provided only by the hardware current limiter at the inverter level.

Serviceability and diagnostics

The serviceability of a special converter project such as Westvaco is greatly enhanced by the use of standard components. ABB is now able to tailor complex special-purpose converters around its standard family of adjustable speed drives. This ensures the supply of spare parts to anywhere in the world. Local ABB technicians are familiar with all major system parts, guaranteeing professional service even for the most specialized converter projects.

Diagnostics have been greatly improved by the second-generation PSR

controller family. An operator's panel with liquid crystal display allows detailed read-out of all system variables and provides messages that clarify alarms or trips. A serial printer connected to the operator's panel automatically prints out all error messages and variables shown on the display in the event of a trip.

The serviceability of the frequency converter system is further improved by an optional link between the PSR controller and a personal computer with modem. The PC modem can be used to access the system by ABB service personnel anywhere in the world. This allows the frequency converter to be analyzed, in operation, over the telephone line by viewing software variables and parameters. Parameter adjustments can be carried out on-line. It is also possible to change or upgrade the program from the remote station.

References

- [1] B. G. Wiley, J. Frisch, P. Dähler, M. Strittmatter, E. Suter: Containerized static frequency converter for back-to-back coupling of two MV grids. *ABB Review* 2/96, 25–31.
- [2] P. Steimer, P. Hartmann, C. Perrin, A. Rufer: PSR – the world's fastest programmable controller with function block language. *ABB Review* 2/93, 21–28.

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