A Modular Subsea Direct-Current Electrical-Power System

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Summary

Subsea processing has been increasingly accepted by the offshore oil and gas industry as a solution to boost production and reduce cost. Accordingly, the subsea power demand is growing to support various processing loads, including pumps and compressors. Depending on the application, the power rating of a field ranges from tens of kilowatts to tens of megawatts, and the step-out distance ranges from a few kilometers to hundreds of kilometers. Considering the hostile and remote environment, a reliable subsea electrical-power system that is suitable for subsea deployment is clearly desired. This paper presents a modular direct-current electrical-power system that is designed for use in a subsea field with medium or long step-out distance. The proposed system consists of multiple modular converters in the subsea station to achieve the required power-conversion functions. It features high reliability, high flexibility, and reduced installation weight. The system operation and protection are presented, and the performance is verified by a laboratory-scale demonstration.

Introduction

The demand for energy is growing worldwide because of the industrialization and economic development in many countries and the growth in population. The US Energy Information Administration projects that the energy demand will continue to increase for the period from 2010 to 2040. Projections in the residential/commercial sector are that the energy demand is expected to grow approximately 30% by 2040, the transportation demand is expexted to grow approximately 40%, and the industrial energy demand is following the same trend.

On the other hand, the harder-to-recover oil and gas reserves and the ever-increasing global demand for oil and gas supply are intensifying the need to deploy technologies for accessing deepsea and remote petroleum resources (IEA 2009; Craig and Islam 2010). Subsea electrification is seen as a key enabler and an integral part of the processing and control of deepwater oil and gas production. Subsea processing systems, such as pumping, compression, and separation, require the deployment of equipment that may include variable-frequency drives, electric motors, switchgears, and uninterruptible power supplies in close proximity to the loads on the seabed, connected by dry- and wet-mate connectors. Their control requires electric actuators and valves for "all-electric" trees and highly reliable power supplies for communication and control at long step-out distances (Rocke 2003; Baerd et al. 2010). For such applications, bulk electrical power needs to be delivered effectively from onshore or offshore platforms, where power is generated, to electric loads on the seabed. The main driver for the power-delivery system is very high reliability with minimal maintenance requirement. In addition, it is desirable that the system be easy to install, be efficient and low cost, and have high power density. The requirements for subsea applications bring enormous challenges, which call for technology innovation and new-system development.

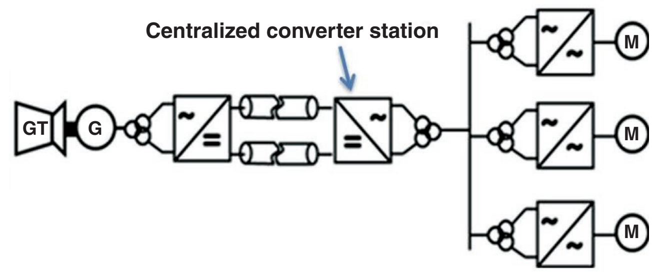

Fig. 1—Modern HVDC technology. (GT = gas turbine, G = generator, and M = motor.)

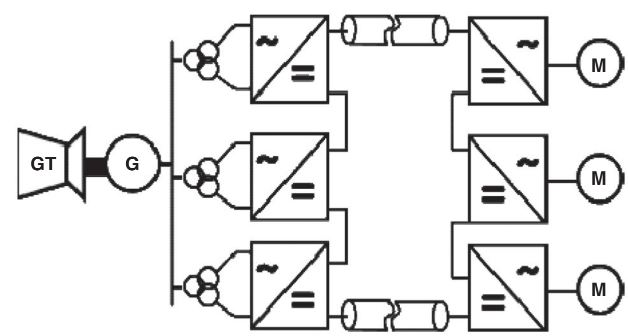

Fig. 2—Example configuration of the modular approach.

From a transmission standpoint, electric power can be transmitted and distributed over long distances either by alternating current (AC) or by direct current (DC). Over long distances, DC is preferred because it is more economical and efficient. DC technology has been well-proved for land-based power-transmission applications at very high voltage and power ratings. However, present DC technology also has limitations. It usually requires centralized converter stations for high voltage and high power conversion, as shown in **Fig. 1.** The converter stations are very bulky, which makes them difficult to transport, marinize, install, and retrieve, and this reduces the system flexibility for future field expansion (Lai et al. 2013).

The DC architecture presented in this paper circumvents the challenges of conventional DC systems for long-distance tiebacks and multiple load systems (Datta et al. 2007, 2010; Zhang et al. 2010; Sande et al. 2012; Song-Manguelle et al. 2012). In contrast

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to the modern high-voltage DC (HVDC) system, the proposed approach achieves the required DC-transmission voltage by stacking a number of modular power converters in series at the receiving end of the DC bipolar cable. The function of the modular power converter is to convert the transmission line HVDC to a medium-voltage level, either AC or DC, and there are multiple options to build the distribution network. For example, the output of the modular converter can either directly feed individual load or support a local grid. The solution down selection depends on the field scenario and the customer requirement. This paper focuses on one configuration only, in which the modular converter is feeding the individual load directly with controllable AC voltage. However, most of the control and protection concepts discussed in the paper can be applied to alternative configurations.

Power Architecture

The example system is shown in **Fig. 2.** It should be noted that other system configurations are possible with the modular concept. In this case, alternating-current (AC) power is generated on an onshore platform and supplied to the transmission and distribution system at the point of common coupling (PCC).

A sending-end converter station is located onshore or on an offshore platform and comprises a series of connected AC to direct-current (DC) converter modules, each module being supplied by a phase-shifting transformer. The transformers provide the required isolation and produce low distortion current waveforms at the PCC of the generation unit; hence, they minimize the size of harmonic filtering. In many situations in which the field is fed from a local generation unit, it is important to have high power quality at the PCC to reduce the risk of exciting torsional resonances in the turbogenerator feeding the system. The AC/DC converter function can be realized by various topologies. In this work, a three-level neutral-point clamped converter is used as an example (Lai et al. 2013).

The receiving-end converter unit consists of DC/AC power modules, which are similar to the AC/DC modules of the sending-end converter unit, but designed to operate in a subsea condition. The DC inputs of the receiving-end modules are connected in series, while the output of each module drives a variable-speed subsea motor through a three-phase transformer. The motors are connected to the converter modules through medium-voltage AC wet connectors.

System Control

With the described topology, the sending-end power-conversion unit is controlled as a current source converter with a variable output voltage. The overall link voltage is controlled from the sending end to keep a continuous link current at a desired value. This current level can be adjusted to satisfy the operational requirements as demanded by the subsea processes.

A modular architecture is used to control the proposed system. Converter modules are symmetrically connected on both ends of the transmission line. Therefore, identical control architectures can be used at the module level (local control). The simplified control architecture of the system is shown in **Fig. 3.** Local module controls are designed to operate autonomously to precisely control power flow from the sending end to the receiving end, and to manage module-level faults.

Converter-level protection is handled by the local converter controller with minimum delay. Direct communication between different receiving-end modules is not necessary. A master system controller coordinates the operation of local controllers, sets references for the sending- and receiving-end controllers, and is designed to manage system-level faults. Communication between receiving-end modules and the master controller does not require a very high sampling rate.

The sending-end power-conversion system controller keeps the transmission-line current at a constant reference value corre-

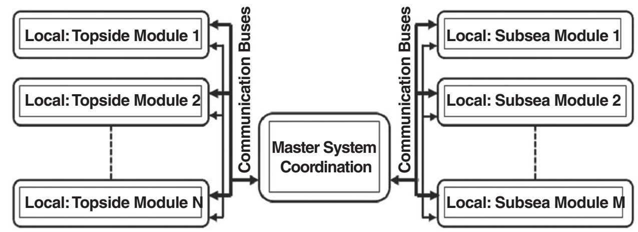

Fig. 3—Control architecture.

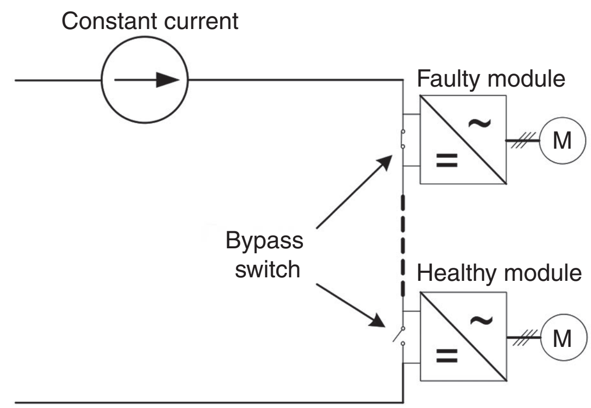

Fig. 4—Bypass switches in the system.

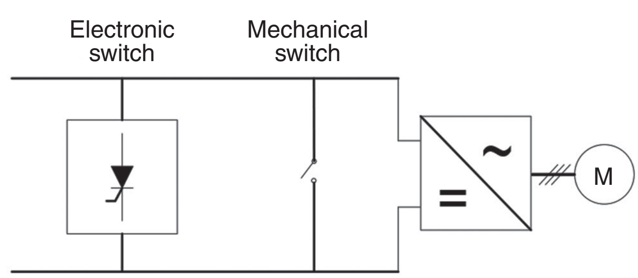

Fig. 5—Hybrid bypass circuit.

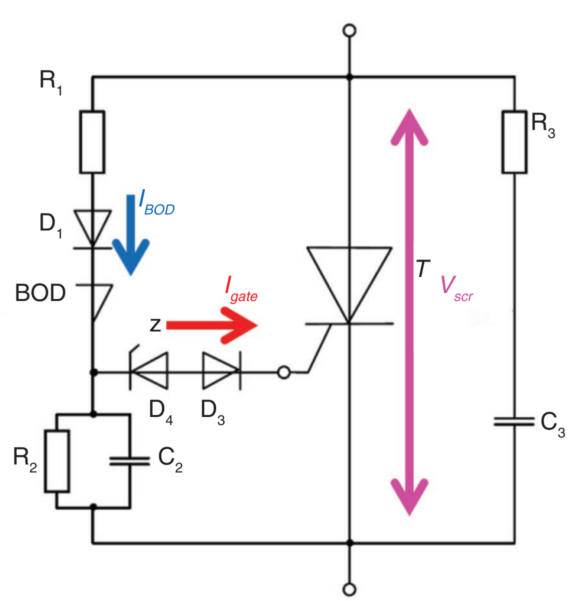

Fig. 6—Conceptual circuit diagram of the electronic switch.

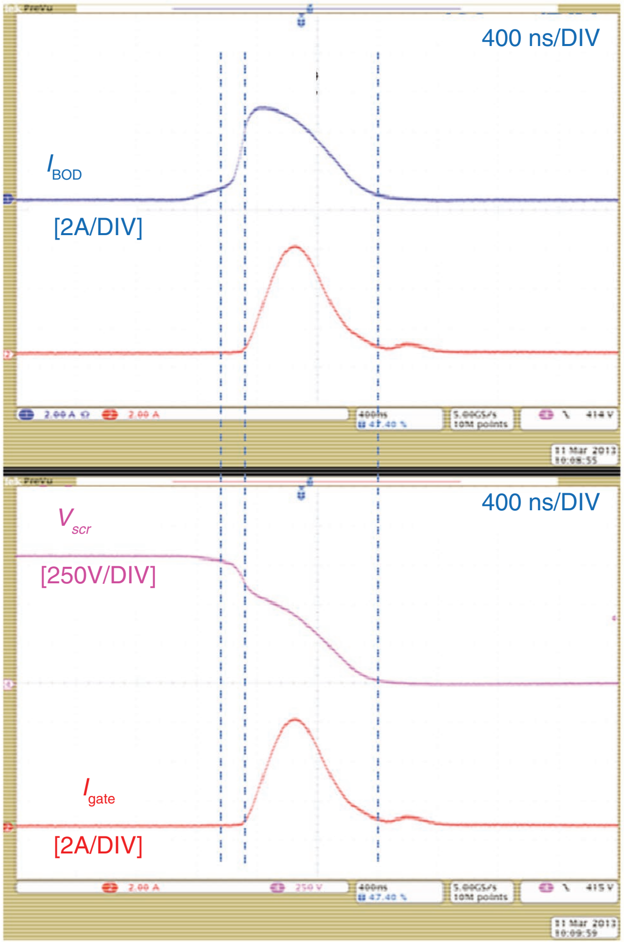

Fig. 7—Experimental results of the electronic switch.

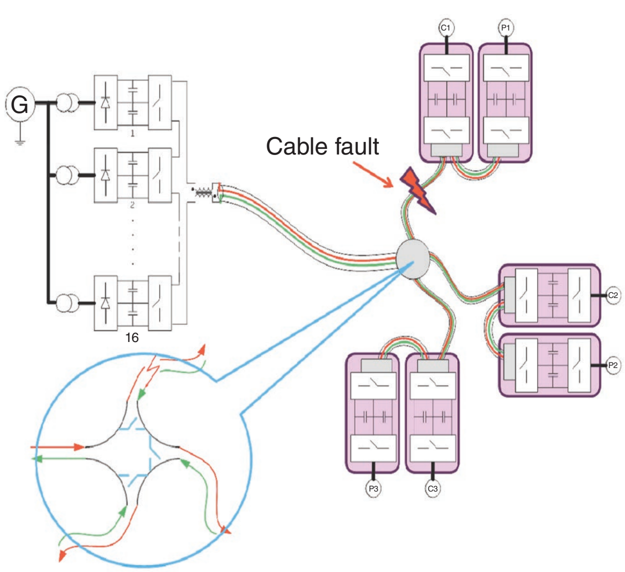

Fig. 8—Clear distrubution-cable open-circuit fault with bypass switch.

sponding to load conditions demanded by the subsea processes. The reference current is compared with the actual transmission-line current measured at the sending end of the transmission line, and the difference is used to generate the voltage command of the sending-end converters through control regulators. To achieve fast dynamic response and maintain the link current constant even at transient conditions, the control bandwidth of the sending-end converters should be much higher than that of the receiving-end converters. To address the challenge, a feed-forward approach is implemented in the controller of the receiving-end converters (Lai et al. 2013).

System Protection

As is well-known, when using a conventional direct-current (DC) distribution network to supply multiple subsea loads, a DC circuit breaker is needed to quickly isolate faulty equipment from the DC bus. Otherwise, the DC-bus voltage could be brought down to zero, which impacts all the loads connected to the bus. However, an on-load DC circuit breaker is not yet available commercially for high voltage and high power.

The example configuration, on the other hand, is a DC system that operates at current source mode. All of the subsea loads are connected in series. The example configuration does not require a DC circuit breaker to break the current and isolate the faulty equipment. Instead, it requires a bypass switch that provides an alternative path for the line current when a fault occurs, as shown in **Fig. 4.**

To effectively protect the example system in a subsea environment and avoid shutting down or damaging healthy equipment during a fault, the design of the bypass switch needs to meet the requirements of high reliability and fast response. As shown in **Fig. 5,** a hybrid circuit concept comprising an electronic switch and a mechanical switch is proposed to address the challenges. The electronic switch is a thyristor-based circuit, which renders ultra-fast fault reaction and smooth switch action. The thyristor will be turned on and bypass the load in parallel a few microseconds after the fault occurs. The mechanical switch, which provides a reliable and low-loss current path for long-term operation, will be closed tens of milliseconds after the thyristor reacts.

The conceptual circuit diagram of the electronic switch is shown in **Fig. 6.** The triggering mechanism is based on the breakover diode (BOD). During normal operation, the BOD has very high impedance and the BOD current (I_{BOD}) is negligible. When the voltage (V_{scr}) across the thyristor (T) is greater than the breakover point of the BOD, the impedance of the BOD will drop sharply to a very small value. Then, a large BOD current (I_{BOD}) will be initiated to charge the filter capacitor, C_2. As soon as the voltage of C_2 is charged higher than the Zener-diode (D_4) clamp-voltage level, a current (I_{gate}) will be generated that flows to the gate of the thyristor, which will subsequently turn on the thyristor. Once the thyristor turns on, the current will flow through the thyristor and the voltage across the terminal will rapidly drop to almost zero. **Fig. 7** shows the experimental results obtained in a laboratory-scale test setup. It shows clearly the entire period of this turn-on transient. In Period 1, the voltage across the BOD exceeds the threshold and the current through the BOD starts to increase and charge the capacitor, C_2. At Period 2, the voltage across C_2 is higher than the threshold of the Zener diode; therefore, the gate current starts to increase and the voltage across the thyristor starts to drop. At the end of Period 2, the thyristor is fully on. Periods 1 and 2 together take approximately 1 microsecond.

In addition to protecting an individual load, the bypass switch can be implemented in other nodes of the system to improve reliability and enhance flexibility. An example with multiple remote fields is shown in **Fig. 8.** In this case, bypass switches are installed in the distribution-switch hub. Each bypass switch is protecting one branch. If an open-circuit fault occurs on any of the distribution cables, the corresponding bypass switch will be closed instantaneously and the faulty portion will be isolated from the rest of the system. The number of single points of failure is greatly reduced.

Discussion

The proposed direct-current power system renders a modular design and simplified distribution network. The subsea converter station consists of multiple small converter modules instead of one

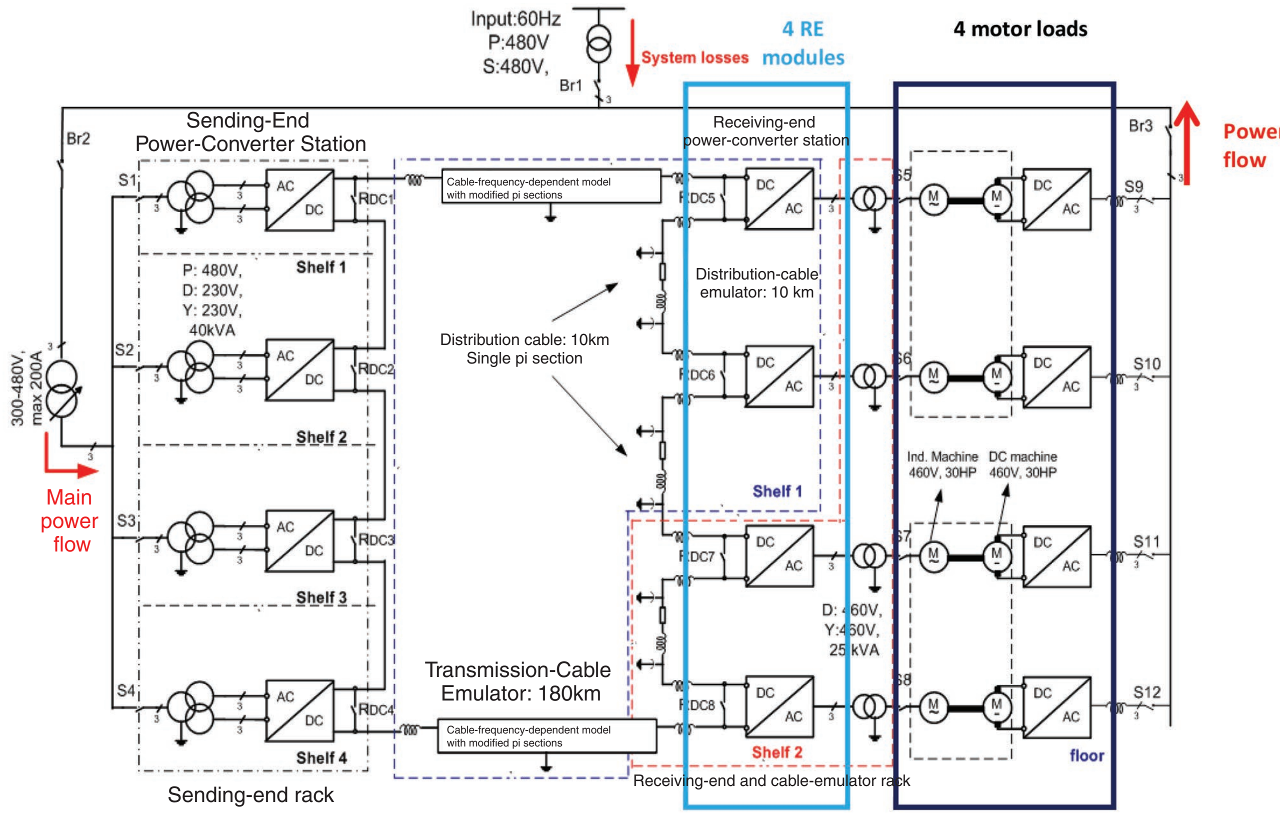

Fig. 9—Schematic of the demonstration system.

bulky centralized converter, which makes it attractive for subsea application. However, the power architecture is new to the industry because all the converter loads are equivalently connected in series. The stability at transient situation and the fault-handling capability need to be verified. To be more specific, the following features of the system shall be proved:

- The operation of the different receiving-end converters is decoupled. Each receiving-end converter should be able to control its own motor load in a stable manner, regardless of the loading conditions and operation of other receiving-end converters connected in series.
- The system is fault tolerant. Any failure occurring in one receiving-end converter should not impact the operation of other healthy receiving-end converters.

Experimental Verification

To verify the feasibility of the proposed modular architecture, a scaled-down version of a hardware-demonstration system, as shown in **Figs. 9 and 10,** was designed, built, and tested. The system consists of four sending-end converters, four receiving-end converters, four motor loads, and cable emulators. The rated direct current (DC) is 40A, and the maximum available DC link voltage is 2.4 kV. The demonstration system is designed to represent the performance of a full-scale system (160 kV/60 MW/180 km) with the per-unit value.

The circuit parameters of the cable emulator were designed through simulation. The electrical and mechanical parameters of a 380-mm^2 Southwire cable were used in a PSCAD^{TM} software simulation to extract the frequency-dependent model of the 180-km cable. From that, a modified model with three pi-sections was built to take into account harmonic frequencies in which skin effects increase the alternating-current (AC) resistance of the cable. The pi-sections were designed such that the cable-emulator impedance matched the actual cable impedance in magnitude and phase for

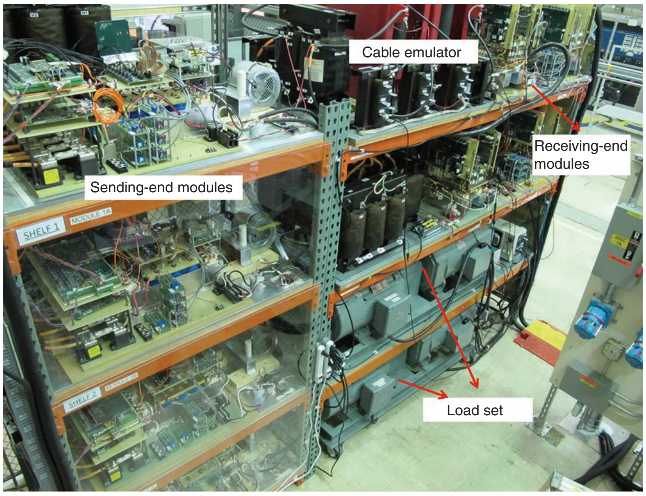

Fig. 10—Picture of the experimental setup

frequencies up to 600 Hz. This corresponds to the bandwidth of the implemented control system. Model results show that a cable-voltage amplification factor beyond 600 Hz is negligible.

Results

Fig. 11 shows the waveforms of system startup. All four motor loads are ramping up together in this case. The torque applied to the motor shaft is controlled to be quadratic to the speed. As the motors speed up, the power consumption increases. As indicated in Fig. 11, the terminal voltage of the sending end increases accordingly, while the link current stays constant. There is a constant difference between the terminal voltage at the sending end and the receiving end. This is the voltage drop across the cable emulators.

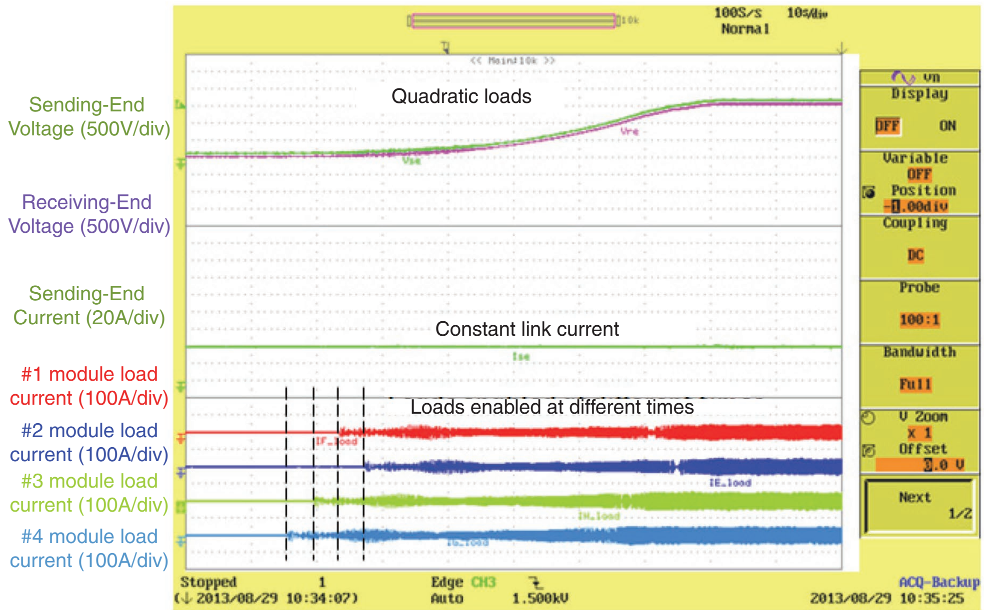

Fig. 11—Test results for system startup.

In other words, this represents the power loss in the transmission-line cable. **Fig. 12** shows the waveforms when all four loads reach steady state. The overall power sent from the sending end is 76 kW, and 72 out of 76 kW is delivered to the receiving end. The power loss in the transmission line is thus approximately 4 kW.

To assess the feasibility of the proposed system, the interaction between different loads is a key aspect that needs to be verified. The experimental results show that each load can be controlled independently, without affecting the operation of other loads. **Fig. 13** shows the steady-state results when four motors are running at different speeds and shaft powers. The link current and the loads are stable. **Figs. 14 and 15** show the test results for transient scenarios. In Fig. 14, one motor is experiencing slow load variation (in tens of seconds) while the others are operating at rated condition. In Fig. 15, the transient is much faster. The load of one motor drops from 100 to 0% instantaneously, and then it starts again after approximately 10 seconds. For the entire period, the other motors operate at full power. As can be seen, the link current is always constant for both cases. Load change in one module will not impact the operation of the other modules.

As mentioned in a previous section, one of the key benefits of the proposed system compared with normal high-voltage direct-current (DC) transmission is that a faulty module can be isolated from the system without breaking DC transmission. The entire system is able to ride through a fault with the bypass switch. This feature is also demonstrated in the experiment.

Fig. 16 shows the case in which the fault occurs to one receiving-end converter. Before the fault occurs, all four receiving-

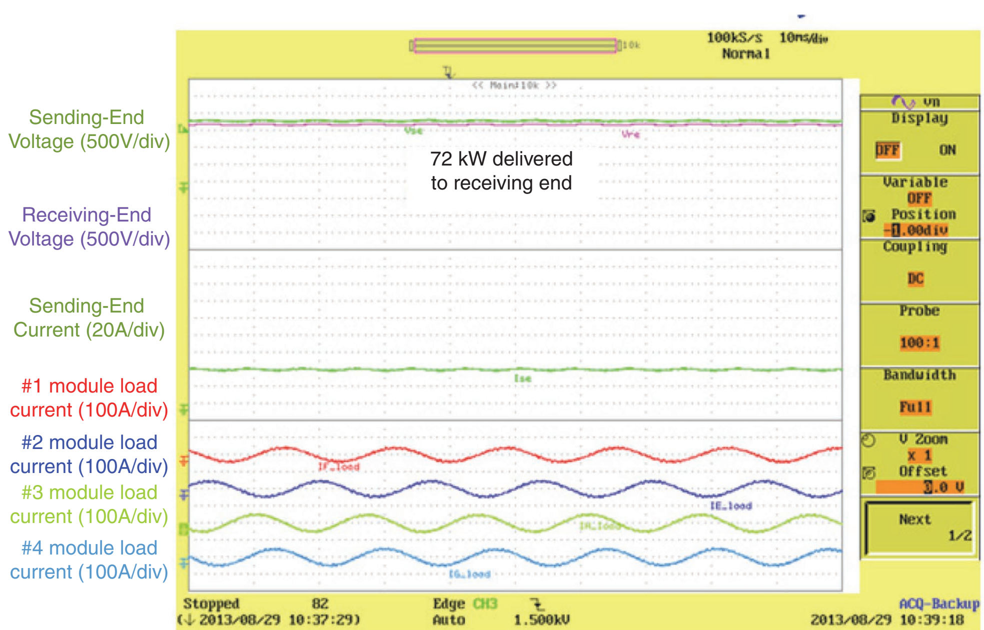

Fig. 12—Steady-state waveforms.

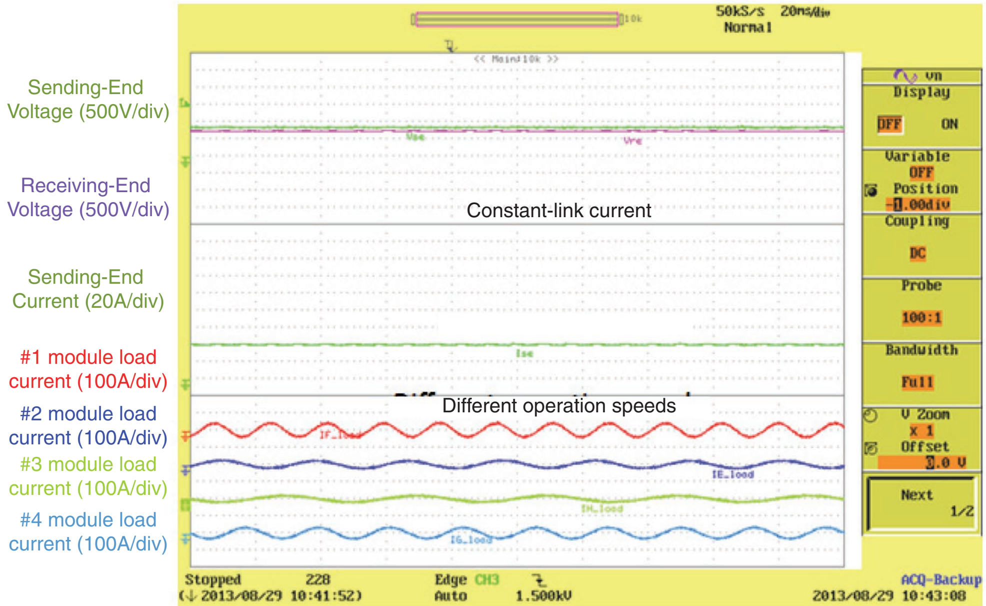

Fig. 13—Motors operate at different speed and load.

end modules are running at full power. After the fault, the faulty module is shut down instantaneously, so that the output alternating current is reduced to zero. At the same time, the bypass switch of that module is turned on, so that the faulty module is bypassed and isolated from the rest of the system.

The bypass operation of the faulty module introduces a sharp voltage change to the transmission-line system. A resonance can be observed in the sending-end and receiving-end terminal voltages. Both the sending-end current and the input current of another healthy receiving-end module overshoot the rated value by 20%. The transient damps down to zero within approximately 50 milliseconds. However, as can be seen in Fig. 16, the operation of the other healthy modules is not affected throughout the transient stage. The effectiveness of the bypass switch is verified, as well as the feasibility of the proposed system.

Conclusion

As the subsea industry moves toward longer stepouts and higher power requirements, there is a growing need for a reliable power-transmission and -distribution system. This paper has presented a modular, direct-current (DC) power architecture for subsea process systems. Multiple modular converters connected in series convert the transmission-line high-voltage DC (HVDC) to a medium-voltage level. The modular design makes the system easier to transport, marinize, install, retrieve, and qualify. In addition, the protection of the proposed system requires only a bypass switch and avoids the need for a subsea HVDC circuit breaker. The experimental results prove that the operation of the converters connected in series can be fully decoupled with proper control. The system is very stable under various transient conditions, and the bypass circuit can protect the system from fault effectively.

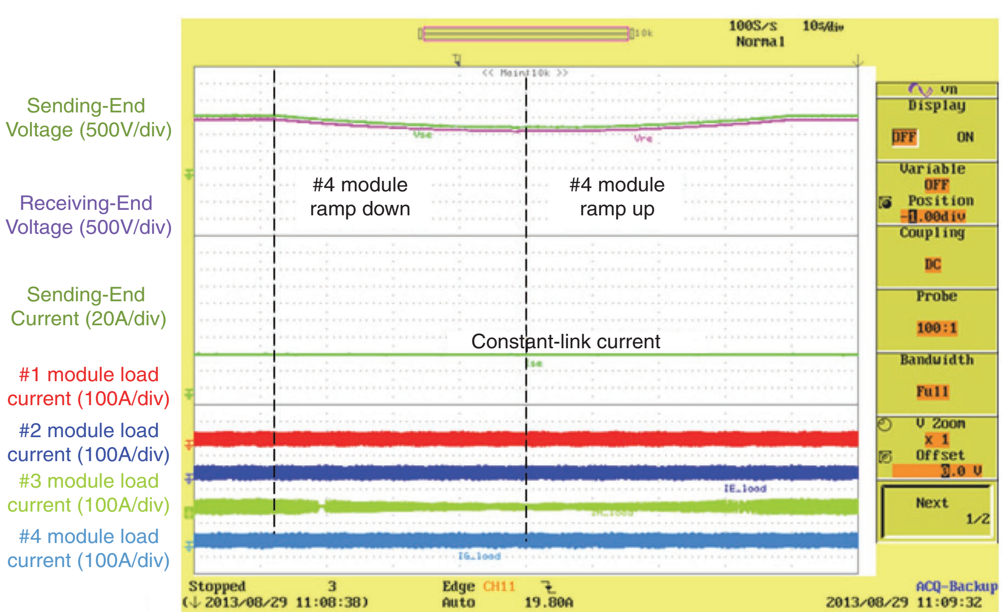

Fig. 14—Slow load transient.

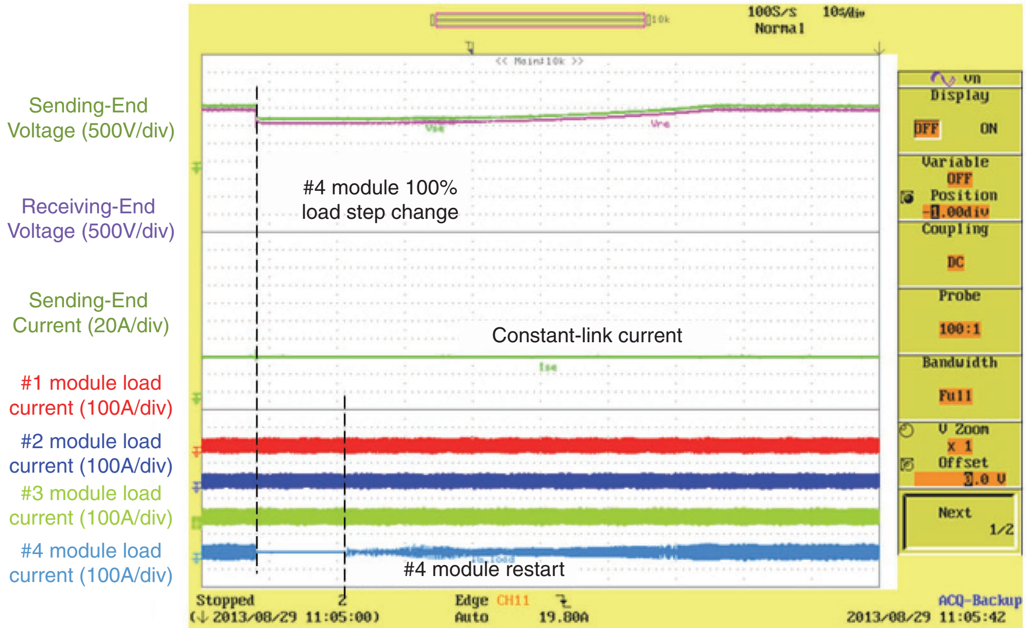

Fig. 15—Fast load transient.

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References

Baerd, H., Normann, T., and Hazel, T. 2010. Ormen Lange Subsea Compression Station Pilot. In *PCIC Europe 2010 Conference Record*,

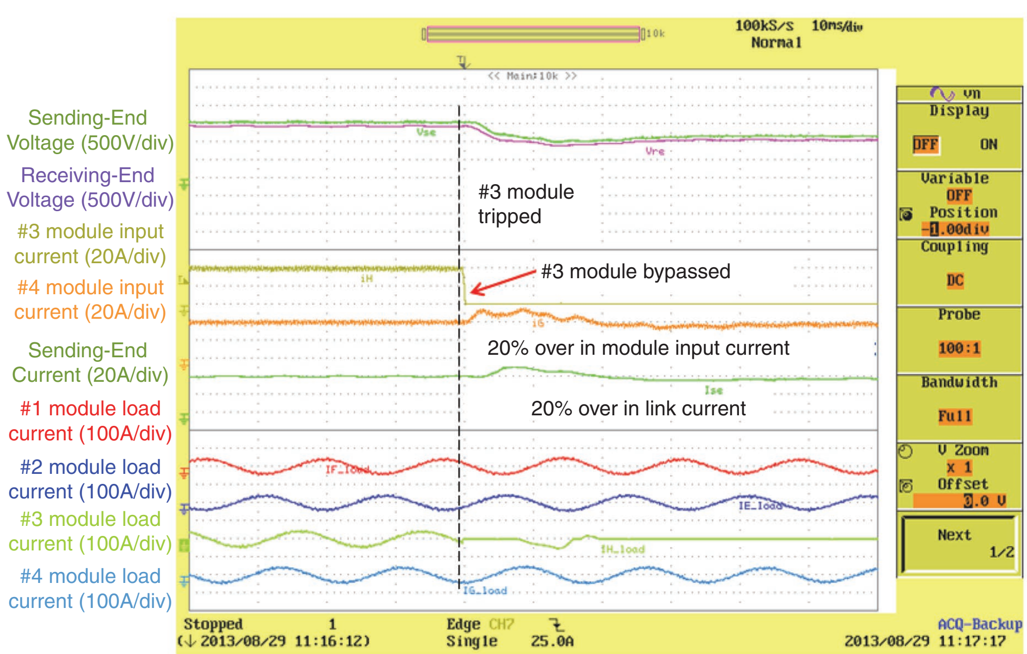

Fig. 16—System test under fault condition.

IEEE Petroleum and Chemical Industry Conference, Oslo, Norway, 15–17 June, 1–9.

Craig, C. and Islam, M. 2010. Integrated power system design for offshore energy vessels & deep water drilling rigs. In *2010 Record of Conference Papers Industry Applications,* IEEE Petroleum and Chemical Industry Conference (PCIC), San Antonio, Texas, USA, 20-22 September, 1–6. http://dx.doi.org/10.1109/PCIC.2010.5666863.

Datta, R., Sihler, C.M., and Zhang, R.S. 2007. Collection and transmission system. European Patent No. EP20070122541.

Datta, R., Sihler, C.M., and Zhang, R.S. 2010. Direct current power transmission and distribution system. US Patent No. 7,851,943.

International Energy Agency (IEA). 2009. *World Energy Outlook 2009*. http://www.worldenergyoutlook.org/media/weowebsite/2009/WEO2009.pdf

Lai, R., Chi, S., Garces, L. et al. 2013. Modular Stacked DC Transmission and Distribution System for Ultra-deepwater Subsea Process. Presented at the Offshore Technology Conference, Houston, 6–9 May. OTC-24183-MS. http://dx.doi.org/10.4043/24183-MS.

Rocke, S. 2003. Subsea Power Transfer - What is the challenge? Presented at the SPE Applied Technology Workshop: Technology for the Next Generation Subsea Systems, Oslo, Norway, 11 February. http://www.spe.no/oslo/html/workshopfiles/papers/Subsea%20Power.pdf.

Sande, G., Rocke, S., Sihler, C.M. et al. 2012. A novel power transmission and distribution system for deep waters and long tiebacks. Presented at the Underwater Technology Conference, Bergen, Norway, 13–14 June.

Song-Manguelle, J., Datta, R., Harfman Todorovic, M. et al. 2012. A Modular Stacked DC transmission and distribution system for long distance subsea applications. In *2012 IEEE Energy Conversion Congress and Exposition*, Raleigh, North Carolina, USA, 15-20 September, 4437–4444. http://dx.doi.org/10.1109/ECCE.2012.6342218.

Zhang, R.S., Datta, R., Sihler, C.M. et al. 2010. Modular stacked subsea power system architectures. US Patent Application No. 20100133901.

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