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Wide Area Synchronized HVDC Measurement Using IEC 61850 Communication

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Abstract

HVDC–Technology is assuming ever greater importance in the transmission of electric power. This requires development of equipment that takes highly precise and time synchronized measurements in DC systems. The data acquisition, the data transfer and a standardized communication interface are important factors to fulfill the requirements for secure and safe power system operation. This paper describes the development of one such system for HVDC measurement with communications interfaces compliant with IEC 61850. Taking the system modeling as the starting point, the finished measurement system and some initial results of the equipment's operation are presented.

Introduction

HVDC systems are growing in importance because of the growing number of offshore wind turbines installed as well as the growing need to transport large quantities of electricity over long distances and between different regions. HVDC minimizes active power losses and eliminates problems caused by reactive power.

Increased use of HVDC Classic, PLUS or Light systems and their increased connection with AC transmission systems is also requiring the use of HVDC wide area monitoring systems. On the one hand, this supports the stability of an HVDC system itself by allowing fast control operations when necessary. On the other hand, such a system is absolutely essential for multi-terminal HVDC systems since they cannot be operated stably otherwise [2] [6]. Figure 1 pictures a model HVDC offshore transmission system in the North Sea that connects different grids and integrates wind turbines. An HVDC wide area monitoring system plays a crucial role in it. Precise measured data and time synchronized instrumentation are particularly crucial for stable system operation since, without them, measured data from different grid nodes could not be compared and a combined state evaluation of the AC and DC grid could not be performed. Development of such a monitoring system requires defining the requirements for the system and its components in keeping with the application and implementing them in development. Both the requirements for the measurement accuracy and the integration of communications equipment in other systems must be factored in and other functions must be provided and implemented.

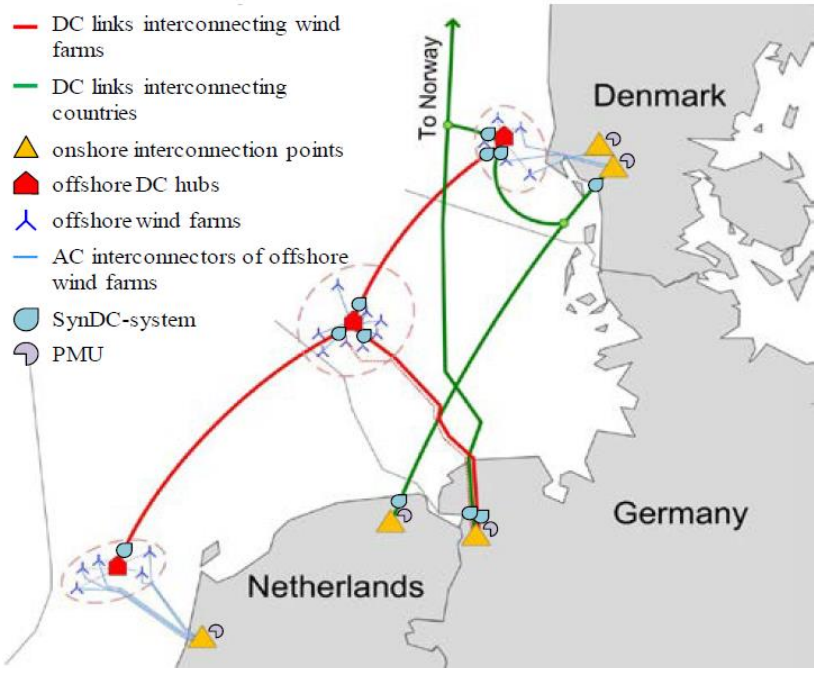

Figure 1 Offshore HVDC system monitoring with synchronized measurement units

Requirements for synchronized HVDC measurement systems

Measurement data acquisition

HVDC lines are usually operated with a voltage-controlled converter station which is operated at the stronger connection point in the AC grid. The converter station at the end of the HVDC line is located at the weaker connection point of the AC grid and operated current-controlled. This regulates the power flow from the current-controlled converter station. The voltage-controlled converter station stabilizes the voltage of the HVDC line.

The construction of more HVDC grids and, in particular, the integration of several wind farms and the connection of different grids, as is planned in the North Sea, is making operation and control more and more complex [3]. Different factors have to be factored in in order to manage HVDC lines and grids reliably and optimally without jeopardizing the operation of the connected AC grid [4]. The power from offshore wind farms has to be transmitted, allowance having to be made for the grid situation at the onshore connection points. Additionally, the transmission of power between the individual converter stations has to be monitored and controlled. The current operating conditions of several systems at nodes at which several HVDC connections are connected with the AC grid or wind farms have to be factored in and employed in control algorithms to ensure that the HVDC grid operates flawlessly and optimally. The independently operating but electrically interconnected systems have to be monitored from a control center. The system parameters have to be known and the electrical parameters have to be measured and communicated. This requires special DC instrumentation that optimizes monitoring and integration in existing AC grid control centers to assure grid stability.

The system requirements for the instrumentation are taken from the operating characteristics of the HVDC lines, the properties of the offshore wind farms and the requirements for the operation of AC grids connected by the HVDC lines. The requirements from the information and communications technology (ICT) used in the control centers are added to this. A distinction must be made between the requirements that make use for local protection possible and the requirements that are essential to the implementation a wide area monitoring system. The requirements for the performance, availability and precision of HVDC instrumentation vary significantly from application to application.

Currents and voltages are the primary parameters of HVDC lines that have to be measured. Time synchronized data acquisition is essential in order to perform a valid and evaluable state evaluation for the complete system, which consists of several converter stations and can contain AC grid connections. The requirements from the time synchronized data acquisition in AC measurement systems, e.g. phasor measurement units (PMU), served as the basis for the minimum requirements for the specification of the requirements for the DC measurement system in order to provide the precision and performance required of wide area monitoring systems (WAMS) for AC grids. The HVDC meters' maximum time synchronization error should not exceed 20µs. What is more, in keeping with SCADA time and in order to be able to use the measurements in the WAMS, the time lag of data transmission up to the control center should not exceed 1 second.

The data transmitted by the distributed time synchronized measurement systems should converge in the grid control center. This data can be used to determine system parameters, which provide information on power flow, equipment loading and, thus, system state. Other variables measured and transmitted by time synchronized DC instrumentation were defined accordingly. These are transmission losses, line impedance, current ripple and power swings. The standardized data acquisition system and standardized interfaces that transmit the data are another requirement that was defined to assure correct transmission and use of measured data. The system structure (see Figure 2) was derived from these underlying requirements.

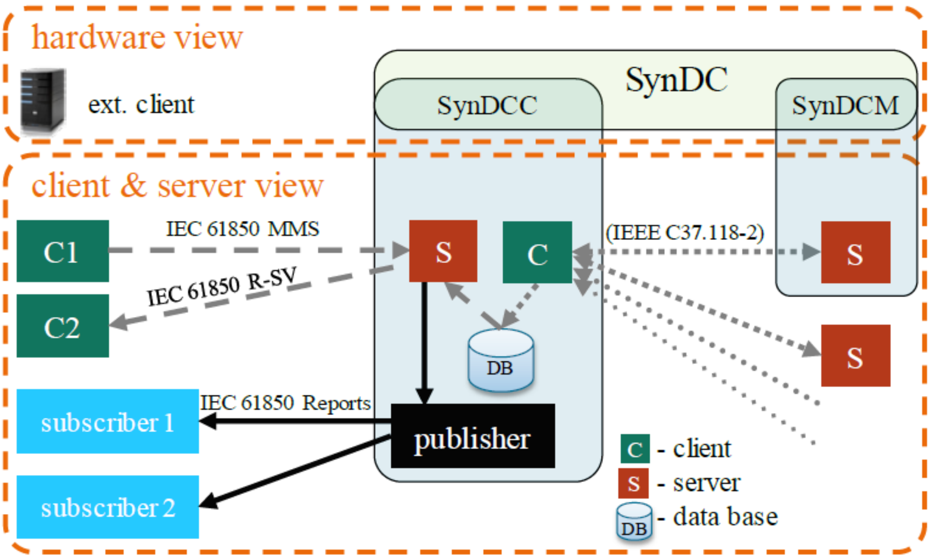

Figure 2 Communication structure in server client presentation

The time synchronized HVDC measurement system consists of individual HVDC meters, a data concentrator and external components. The interfaces between the individual components are implemented in compliance with standardized communication systems and explained in more detail below.

Communication and interoperability requirements

Functional and non-functional requirements which govern the system components' communication and interoperability are specified for the wide area monitoring system (SynDC system). All of the measurement units (SynDCM) have to deliver time synchronized measurements using standardized interfaces and protocols for correct operation. This achieves high interoperability between the individual meters and the monitoring system.

Functional requirements:

- Meters have to be remotely configurable.
- It must be possible to start/stop measurements.
- Measured AC/DC data (power, voltage, current, impedance) must be continuously transmittable.
- It must be possible to validate measurements' correctness.
- Forward events must be automatically detectable.
- Measurements must be archived.
- It must be possible to perform state evaluations of offshore HVDC systems.

Non-functional requirements:

- Measured data must be protected from third party access.
- Meters must be reliable (redundancy).
- Meters must be time synchronized (with a maximum inaccuracy of 20 µs).
- The time lag of a state evaluation in the WAMS must be less than 1second.

Synchronized DC measurement unit: architecture and functions

System architecture

The wide area monitoring system (SynDC system) is specifically designed to be implemented to monitor and evaluate an HVDC grid's state and to connect data systems with AC grids for integrative management (e.g. synchronous data operations) (see Figure 3).

The SynDC systems architecture consists of three system components distributed on independent pieces of equipment. The control center and the monitoring system it contains serve as the client at which all data from the individual converter stations converge. Encryption mechanisms compliant with IEC/TR 61850-90-5 secure communication [11]. Encryption compliant with IEC 62351 [13] is dispensed with for reasons of performance. Pieces of SynDCM equipment can communicate either directly with external pieces of equipment in compliance with IEC 61850 or with the SynDCC server in compliance with IEEE C37.118 [12] (see Figure 3). Since IEEE C37.118 sets forth a message's contents, i.e. parameters, for AC measurements, the standard has to be modified for DC measurements for SynDCM equipment. Concretely, the configuring frame 3 and the data frame have to be modified in keeping with the requirements to create a proprietary version of the standard to transmit measured DC data. The system is designed so that every converter station has a SynDCC proxy server that receives the measured data from the individual meters in the station and processes them further for the monitoring system (see Figure 4).

The central distribution components in the SynDC system are the SynDC concentrators (SynDCC) implemented as communications middleware between the meters and a monitoring system. Every converter station has such a concentrator. IEC/TR 61850-90-5 also specifies this configuration as an option for communication between meters and a monitoring system [11].

An advantage of this communication specification is the implementation of safety requirements without having to equip the particular measurement units with additional security systems. This security is achieved by the controllable communications channel in a converter station between the SynDCC and the measurement units and the encrypted communication between SynDCC and control center. Furthermore, the measurements can be sent to more than just a monitoring system. Generally, like protective systems, other components, so-called subscribers, ought to receive measurements by a publisher "event trigger". The event trigger component in the SynDC system uses reports as defined in IEC 61850-7-2 to communicate with the particular subscriber [9].

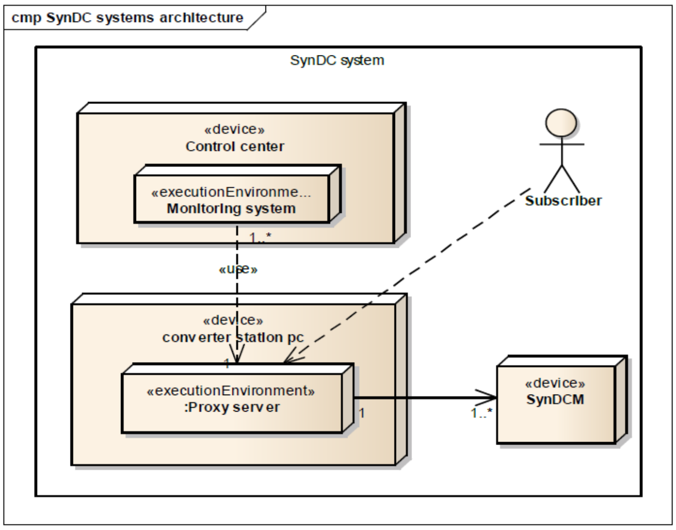

Figure 3 SynDC systems architecture

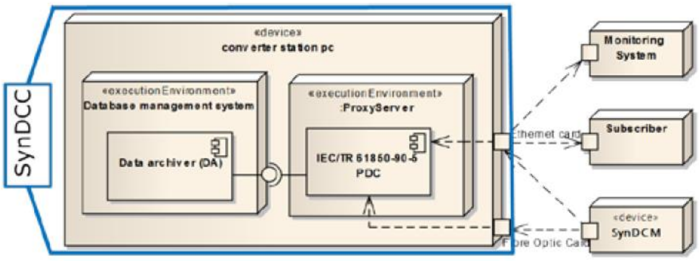

Figure 4 Structure of a SynDCC and actors

Another function of the SynDCC is its persistent measured data management by means of a data archiver (DA). This component must be suitable for mass data management, thus making the use of database technology or even data warehousing technology advisable. It can manage measurements of several terra bytes. Furthermore, a database schema created specifically for this purpose assures fast access of measurements.

The IEC 61850-90-5 phasor data concentrators (PDC) component combines individual meters' measurements and forwards them to the DA for, among other things, archiving. The PDC additionally provides an interface for external actors and systems, through which they can retrieve measurements. To this end, the PDC component employs not only services and data models compliant with IEC 61850-7-2 [9] and IEC 61850-7-4 [10] but also specifications compliant with the new standard IEC/TR 61850-90-5, which are intended for the integration of PMUs.

IEEE C37.118 Interface

The standard IEEE C37.118-2 [7] is used for the transmission of a PMU's synchronized measurements to PDCs and other applications [1]. This standard defines a very lean and easily implemented, message-based protocol that keeps unnecessary data from been sent to a client. A drawback of this standard is its lack of requirements for secure transmission of the measured data. Many meters also lack VPN encryption, which would protect the communications channel.

Since its design is standardized for the transmission of measured AC data, a new data frame or configuring frame is essential when a piece of SynDCM equipment is used in the SynDC system. The SynDCM contains all of a PMU's communications functions plus additional functions to transmit measured DC parameters mapped by the DC data frame and the CFG-3 (DC) frame (see Figure 5). For the distinction of messages between DC or AC measurements it will be assigned a new version number into the field sync. All DC measurements will be characterized by the appropriate version number (00|11b). There is no plan to include remote meter configuration, as in the standards IEEE C37.118, in the defined functional requirements. This means that a proprietary system must be used to implement this requirement.

IEC 61850 Interface

Harmonization of these two standards has been initiated in recent years in order to integrate established PMUs in a grid control system in conformance with IEC 61850, too. Some initial results of these efforts are the division of IEEE C37.118 (2011) into a pure message format (Part 2) [7] and requirements for PMUs (Part 1) [12].

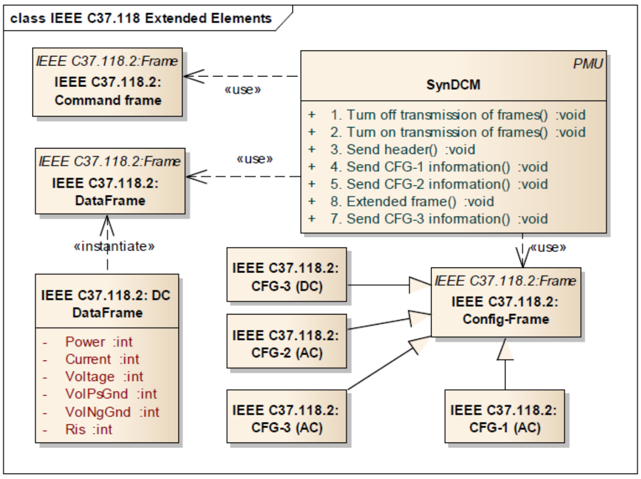

Figure 5 Extension of a DC data frame and CFG-3 frame following IEEE C37.118-2

Furthermore, IEC 61850 published the IEC/TR 61850-90-5, which deals with PMU integration as well as necessary modifications in the respective sections of IEC 61850. Additionally, technical report defines seven use cases under which the use of PMUs is conceivable. The following three use cases from the technical report are implemented for the SynDC-System and were incorporated in the requirements for the PDC component [11]:

- 5.6 Situational awareness
- 5.8 Archive data (event & continuous)
- 5.9.6 Phasor Data Concentrator

Based on the analyzed requirements from the use cases, two logical nodes (MMXU and MMDC) were selected [10]. This means that the PDC uses the logical nodes MMXU to map a PMU, which delivers AC measurements, and uses the MMDC to map DC measurements for the monitoring system (see Figure 6). The PDC component additionally provides two control blocks:

- Routable Multicast Sampled Value Control Block (R- MSVCB)
- Unbuffered Report Control Block

The R-SVCB is an extended sampled value control block specified in the technical report [11]. The event trigger component provides an unbuffered report control block to event-driven measured value transmission, which, depending on the configuration, forwards them to the appropriate subscribers.

SynDC and SynDCM system implementation

A DC measurement system with options for analog and digital measurement of currents and voltages as well as diverse communications interfaces was employed as the hardware platform to implement the system. GPS time synchronization like that used for PMUs in the AC grid was employed. The specified interface configuration and communications architecture were implemented in a test bench. The measurement system was tested and optimized for the predefined requirements. Test criteria include precision, system performance and interface conformity. DC and AC measurement systems are used in conjunction with the data concentrator to test them.

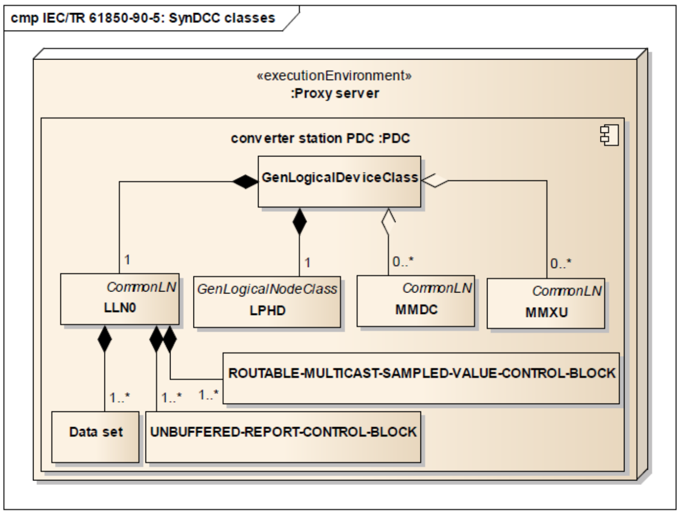

Figure 6 Requisite logical nodes and control blocks

Results

The first measurements have been taken with the implemented prototype system to verify that it functions correctly. Correct, time synchronized acquisition of data was especially emphasized. Another criterion in the first tests was the output of measured data, in compliance with IEC 61850 [8]; using simple read polling in the first instance and the reporting function in compliance with IEC 61850-7-2 in the later extension[9]. A hardware model developed to test HVDC transmission was used to test the measurement system [5], [6]. The SynDCM measurement system was connected to the HVDC transmission model to measure the parameters of DC side current and voltage. A commercial tool was used to test the underlying function of the SynDCM's reading of measured data by means of an IEC 61850 interface. Figure 8 shows the tool's graphical user interface. It displays the configured logical data model and all of the transmitted data on power, current, voltage and impedance measured by the SynDCM in the DC transmission line. Typical data attributes for the IEC 61850 data model, representing instantaneous value, the deadband value (used for reporting) and the related timestamp, are recognizable. The quality indicators are also presented in the data attribute q.

This system was used to take first test measurements on the aforementioned hardware model of a HVDC line. A sample recording of the measured voltage is shown in Figure 9. Different adjusted voltage levels and a final shutdown of the system are shown recorder over a time of about 25 seconds.

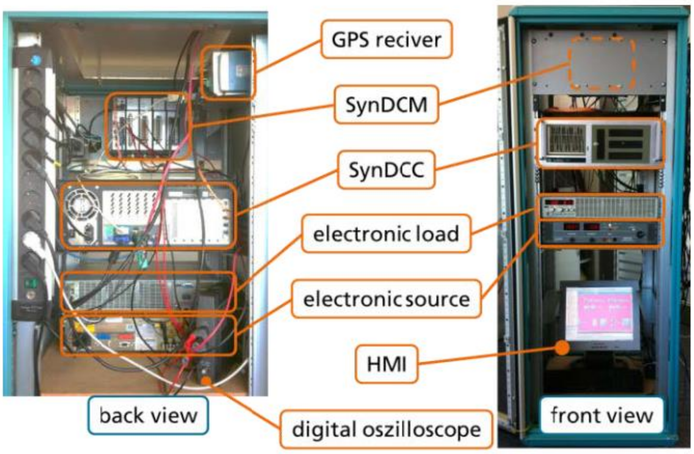

Figure 7: Laboratory test bench with SynDC system

Although the measured data can already be transmitted, more work is still need to complete the system. For instance, the reporting function, a core component of the standard IEC 61850, has not yet been implemented in the system fully satisfactorily. Furthermore, the system also needs to be extended so that not only the already available measured data but also other derived values and, where necessary, data relevant to safety and security can be computed and output on the system.

Conclusion

The future trend toward increased production of power by offshore wind farms is making the use of HVDC technology and thus also the use of appropriate monitoring and protection mechanisms essential. Synchronized instrumentation that outputs data in compliance with standardized protocols can make this happen. It will be possible to implement appropriate measurement systems once the requisite range of functions is clearly defined and provide the basis for creating appropriate systems architecture. This will make it possible to integrate different components that perform different tasks, e.g. synchronized measured data acquisition, communication in compliance with IEEE C37.118, communication in compliance with IEC 61850, local measured data analysis, error handling, for the purpose of a modular design. Initial tests have demonstrated that the prototype meets the requirements made and correctly transmits measured data in conformance with standards.

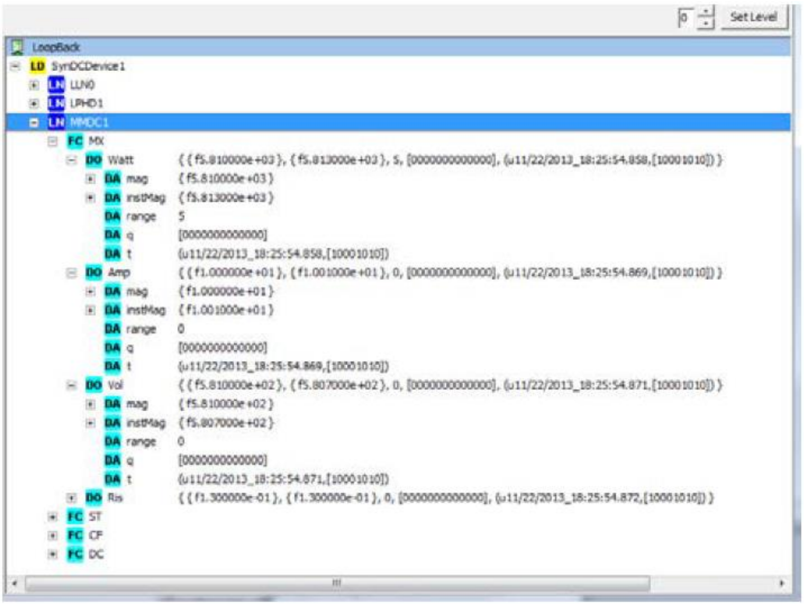

Figure 8 Reading data from the IEC 61850 interface of the SynDCC

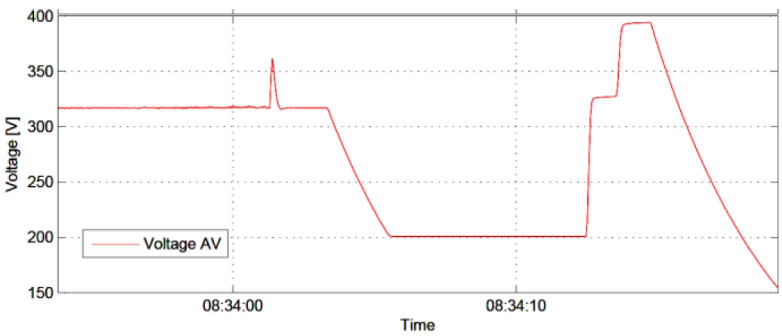

Figure 9 Sample Measurement of HVDC voltage

Even though a few aspects of implementation remain open, an excellent basis for interoperable systems for use in HVDC wide area monitoring systems has been established. refinement and complete applied test scenarios and an analysis of its precision and real time capability still lie ahead and will be pursued in future research. The findings will be presented in future publications.

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