Modeling Solid State Transformer in IEC 61850

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Abstract- **Solid state transformer (SST) is a bi-directional electricity exchange device that is proposed to accommodate widespread Distributed Renewable Energy Resources (DRERs) and Distributed Energy Storage Devices (DESDs) into the existing distribution systems.**

IEC 61850 is the leading standard for power system communications and affords the integration of devices of different types into the system. It is obvious that SST has to be modeled with IEC 61850 in order to support its incorporation with DRERs and DESDs to the distribution system.

In this paper a model of a SST and its mapping to IEC 61850 is presented. Existing logical nodes and their use are considered and a new logical node is also presented.

Keywords-solid state transformer; FREEDM; modeling; IEC 61850; logical node

I. Introduction

Power systems in their existing state cannot keep step with challenges like depleting oil resources, global warming, environmental pollution, increasing energy demands, need for energy independence from imported crude oil and an overall economic stability. To lessen the problems the usage of Distributed Renewable Energy Resource (DRER) systems which are interconnected with the distribution power systems is essential [1]. DRER is defined as a small-scale renewable electric energy resource located next to and connected to the load being served either with or without an electric grid interconnection. The distributed generation includes solar arrays, wind turbines, fuel cells, and micro-turbines. The intermittent nature of these DRERs requires an appropriate energy storage infrastructure which is used as an electricity source during times of their unavailability. To accommodate the DRERs and Distributed Energy Storage Devices (DESDs) into the existing grid, there are changes required in the power system technology like using solid state transformers (SST) [2].

SST is a bi-directional electricity exchange device that is becoming an alternative to replace the conventional transformers [3, 4]. High-frequency converter, the heart of SST is now feasible due to Silicon carbide (SiC) materials. The new transformer does not face the undesired features of the ordinary one such as bulky size, regular maintenance and power quality vulnerability. Enabling the unity power, not being affected by voltage sag or swell, potential removal of circuit breaker, harmonic elimination, and fast fault detection and protection are the other advantages of SST [4].

The proposed Future Renewable Electric Energy Delivery and Management (FREEDM) System is an example of an efficient power grid integrating highly distributed and scalable alternative generating sources and storage with existing power systems[2]. In a FREEDM system DRERs, DESDs, and consumer loads are the subsystems connected by the SSTs. These subsystems may have different interface types (ac or dc), different voltage levels, different power levels and different power quality requirements. The SST acts as a smart plug-and-play interface for transforming and distributing electric energy from these various different subsystems, some via the AC port and others via the DC port. However, along with the power management control functions of SST, a reliable and flexible communication protocol is needed to enable a very dynamic plug-and-play grid.

IEC 61850 is the dominant communication standard of power system and allows the integration of devices of different types into the power system [5]. It uses advanced modeling techniques to represent protection, control, monitoring devices, services and corresponding data used in substation automation systems. Moreover, the data and service modeling techniques are independent of the underlying protocol which carries the actual data through the network. The same approach has been extended to other parts of the power system. IEC 61850-7-420 provides IEC 61850 extensions or logical nodes to be used to model decentralized energy resources [6]. These are applicable to central-station generation installations that are encompassed of groups of several units of the same types of energy conversion systems e.g. photovoltaic and fuel cells. In order to support the integration of SST with DRERs and DESDs to the distribution system, it is required that SST also to be modeled with IEC 61850. All loads and DRERs and DESDs will communicate with the SST using this standardized communication protocol.

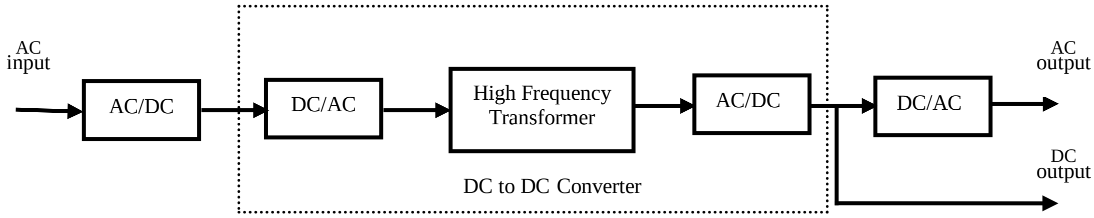

Fig. 1. Principle diagram of solid state transformer

This paper describes first the configuration and those functions of SST required for its mapping to IEC 61850. The model of SST and its integration in an IEC 61850 based system is then presented. Existing logical nodes and their use are first considered. Finally, the new required logical nodes are introduced and described.

II. Configuration and Functions of SST

A. SST Fundamental Configuration

Fig. 1 presents a generalized schematic of a SST with primary and secondary static converters and high frequency transformer [1]. As can be seen, the power-frequency input sin wave voltage from the grid is first converted into a high frequency signal by the primary side AC/DC and DC/AC converters, and then, magnetically coupled to the secondary. In the secondary side, the high frequency signal is first converted to a DC signal and then transformed into a power-frequency waveform. DRER, DESD, and load can be connected to the AC output or they can be alternatively connected to the DC output voltage. As it was already mentioned SST is a bi-directional energy flow device, i.e., each converter in the system has a dual role, AC to DC converter (rectifier) and/or DC to AC converter (inverter). Considering the mentioned conception each port of SST can be an input and/or output terminal, depending on the requirements and direction of the energy flow.

B. SST Primary Functions Visible to Communication

The key notion in modeling with IEC 61850 is that the model contains just the functions that are observable to the communication. A black box object with true inputs and outputs and internal signals that are not observable to the outside world should not be integrated into the model [5]. Considering the above concept the SST configuration in Fig. 1 can be revised to make it suitable for mapping to IEC 61850.

The SST typically includes a high-voltage AC to DC power conversion stage, a high-frequency DC/DC converter stage to produce a regulated DC bus, and a DC/AC stage to produce a low voltage regulated AC bus. From the above three different stages of power conversion in SST, the DC to DC converter stage, consisting of two middle converters and the high frequency transformer, is not visible to the communications. Merging this stage with the AC/DC conversion stage will reduce the model to the model shown in Fig. 2(a). With this new configuration, SST is essentially a three-port power exchanger and energy router. Fig. 2(b) shows the same configuration when the SST is used to deliver energy from the local resources to the grid. As it can be seen in Fig.2 each converter is a bi-directional device, i.e. AC to DC and/or DC to AC converter. The regulated DC bus is an input and/or output port for both converters in Fig.2.

In a normal operation of SST all three different ports in Fig.2 are active. However, there are some situations that one port out of three is out of service. There could be a case that power from the electric utility is no longer present and SST is disconnected from the grid (islanding condition) and energy is exchanged between the local subsystems through the right hand side converter and the DC bus in Fig. 2. In this case the left hand side converter will be switched off and disconnected

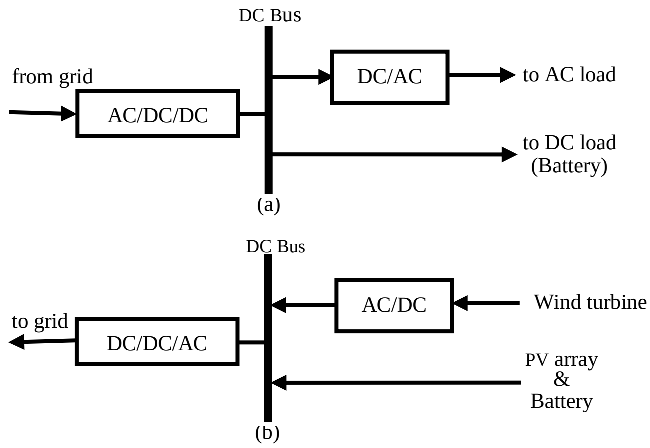

Fig. 2. SST bi-directional functional diagram: (a) Energy delivery from grid to the local loads, and (b) Energy delivery from local DRER and DESD to the grid

from the grid.

C. The Virtual Circuit Breaker Concept

One of the most important advantages of SST is that there will be no circuit breaker needed before and after the transformer like in conventional one [4]. Due to the operation of semiconductors, once SST has ceased to operate, no power will pass the high frequency transformer. Hence, SST also acts as a circuit breaker. This may be called as a *Virtual Circuit Breaker*. This concept should also be considered when SST is modeled with IEC 61850.

D. SST Secondary Functions Visible to Communication

1) *Control Functions:* The grid side high voltage port of the SST is directly connected with the primary system. To prevent harmonics from being injected to the grid, the current should be sinusoidal and in phase with the grid voltage to achieve unity power factor. To match the demand, this stage is controlled as a controllable current source. It also provides active and reactive power control or power/frequency control for the grid side port.

SST regulates the low-voltage AC and DC bus voltages and ensures that the power quality and harmonics of the ac side current meets utility requirement such as IEEE 519.

2) Protection Functions: SST automatically operates like a current limiter because it can limit the current through proper control of the DC/AC converter, or it can trip based on standard I2t curve if the DC/AC converter is designed with proper capacity. It is equipped with internal sensors, which shuts down the converters by removing the gate signals in case of a component fault. In addition, SST is equipped with over current protection, which blocks the converters. These results in a reduction of SST produced current to zero and a collapse in output voltage. SST is also equipped with under voltage protection, which also blocks the converters when the high voltage supply is reduced [3].

III. SST MAPPING TO IEC 61850

Fig.3 shows a schematic of proposed mapping of SST to IEC 61850. Below is the description of different logical nodes in Fig. 3.

1) The ZBCV logical node (LN) defines the characteristics of the bi-directional converters used in SST. Rectifier LN (ZRCT) and inverter LN (ZINV) are used to build this new LN. This LN is described in detail in the next section.

2) LLN0 is the logical node device for SST that includes common information for logical device like device name plate, health and mode.

3) MMXU and MMDC are used to acquire AC and DC values at different ports of SST [7, 8].

4) CSWI is the switch control LN and is used to control the virtual circuit breaker operation of SST converters.

5) CPOW, the point-on-wave breaker controller LN provides the functionality to close or open the external switches at a certain point of the voltage and current wave. This LN works together with the CILO (interlocking function) and CSYN (the synchronizer controller) LNs to perform the interlocking and/or synchronization functions between the SST and the grid and/or the subsystems.

6) AVOC is the automatic function to keep the voltage of the AC and DC ports at a specific set point that is determined by ZBCV logical nodes.

7) ARCO is the automatic function to keep the reactive flow of SST a certain set point that is given by ZBCV logical

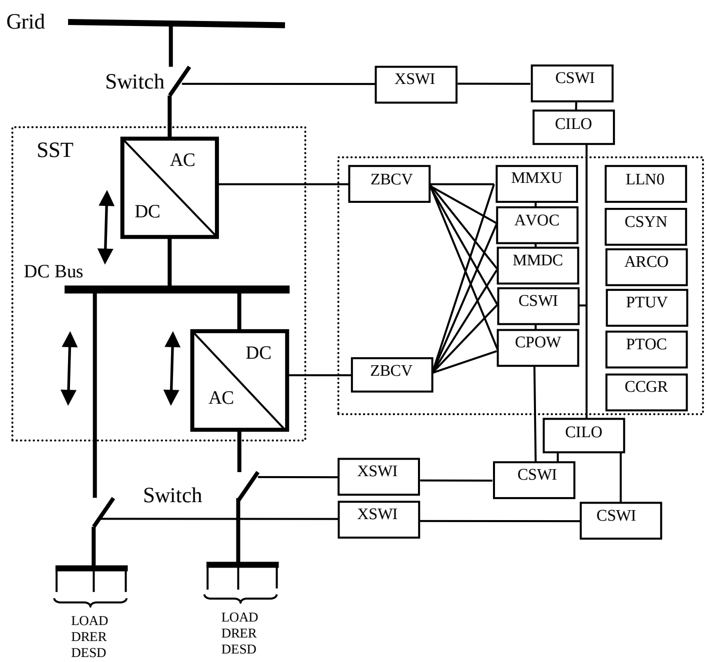

Fig. 3. SST mapping to IEC 61850

node. This can be used to set the power factor to a predetermined value, e.g., 1.

8) PTUV and PTOC are the functions to protect the SST against under voltage and over current situations in the grid.

9) CCGR logical node is used to control the cooling equipment of the SST.

IV. Definition of the new ZBCV logical node

Ref. 6 includes ZRCT and ZINV logical nodes which are used to characterize rectifiers and inverters, respectively. The converters used in SST are bi-directional converters, i.e., they may be a rectifier and/or an inverter. And hence, neither of the above LNs does completely cover the SST converters; however a combination of those two LNs may solve the problem.

To allow the users of the IEC 61850 standard to use the modeling method, the basic models like types and Common Data Classes, and Data Objects, IEC 61850-7-1 defines a standard rule on how to cope with required extensions [9]. Two different approaches are offered to overcome the problem. The first method suggests that use the an existing LN and add some data to cover all requirements. The other method is that to define a new LN and use the standard data already available through the other LNs. The second approach is used in this paper as the rectifier and the inverter perform opposite functions and neither of the related LNs can be used for a bi-directional converter. However, a combination of the data in those LNs may be used to define a new LN.

Table 1 (see the appendix) shows the new proposed LN to characterize a bi-directional converter. The LN is named as ZBCV which is inherited from the logical-node class. Here, Z denotes to the LN group for further power system equipment. B stands for bi-directional and CV is used to describe "converter". The characteristics of the new logical node are described in Table 1. A combination of data from ZRCT and ZINV LNs are used in this LN to cover both the rectifier and the inverter functions. However, there are still some new added data and some changes in the data names that are described below.

1) In the conversion type data a value is added to describe a DC/DC/AC type converter. This is for covering the left hand side converter in Fig. 2(b).
2) The name OutFilTyp in the filter type data has been changed to FilTyp due to the bi-direction functions of the converters.
3) In order to cover both rectifier and inverter functions of converters, A and D letters have been added to the data names in the limits and setpoints of input and output currents and voltages, for AC and DC signals, respectively.

V. Conclusion

An equivalent model of a SST and its mapping to IEC 61850 standard has been developed. Existing logical nodes and their use were considered. A new logical node was also introduced. Existing standard data were used with or without modification and new required data were also defined. Future work will include modeling of SST functions using internal mechanisms of IEC 61850 and external means, like IEC 61499 architecture, as proposed in [10].

VI. Acknowledgments

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VII. References

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APPENDIX

TABLE1. BI-DIRECTIONAL CONVERTER LOGICAL NODE (ZBCV)

ZBCV class				
Data object name	**Common Data class**	**Explanation**	**T**	**M/O**
LN Name		Is inherited from logical-node class		
Data				
System logical node data				
		LN shall inherit all mandatory data from common logical node class		M
		Data from LLN0 may optionally be used		O
CmutTyp	ENG	Type of commutation: (As described in ZRCT and ZINV LNs in Ref. 6.)		M
IsoTyp	ENG	Type of isolation: (As described in ZRCT and ZINV LNs in Ref. 6.)		M
VRegTyp	ENG	Type of voltage regulation (As described in ZRCT and ZINV LNs in Ref. 6.)		M
ConTyp	ENG	Conversion type: Value – Explanation 0 – Not applicable/ unknown 1 – AC to DC 2 – DC to AC 3 – AC to DC to DC *4* – *DC to DC to AC* 99 – Other		O
CoolTyp	ENG	Type of cooling method: (As described in ZRCT and ZINV LNs in Ref. 6.)		O
ACTyp	ENG	AC system type (Single, two or three phase, as described in ZRCT in Ref. 6.		O
FilTyp	ENG	Filter type, as described for OutFilTyp data in ZRCT LN in Ref. 6.		O
Settings				
PQVLimSet	CSG	Active curve characteristic curve for PQV limit		M
OutWSet	ASG	Output power setpoint		M
OutVarSet	ASG	Output reactive power setpoint		M
OutPFSet	ASG	Power factor setpoint as angle		O
OutHZSet	ASG	Frequency setpoint		O
InAALim	***ASG***	***Input AC current limit***		***O***
InDALim	***ASG***	***Input DC current limit***		***O***
OutAVSet	***ASG***	***Out put AC voltage set point***		***O***
OutDVSet	***ASG***	***Out put DC voltage set point***		***O***
OutAALim	***ASG***	***Out put Ac current limit***		***O***
OutDALim	***ASG***	***Out put DC current limit***		***O***
InAVLim	***ASG***	***Input Ac voltage limit***		***O***
INDVLim	***ASG***	***Input DC voltage limit***		***O***