CIGRE-112 **2019 CIGRE Canada Conference**
Montréal, Québec, September 16-19, 2019

Smart Transmission Grid Based on Smart Power Lines with Independent and Redundant Optical Fiber Network

PIERRE COUTURE *, *Senior Member, IEEE*
Hydro-Québec
Canada

SUMMARY

This paper presents a novel Smart Transmission Grid (STG) architecture. This architecture is composed of a network of Smart Power Lines (SPLs) in which the switching modules (SMs) are optically linked through a redundant and independent optical-fiber network. An SPL is a conventional bundled power line (e.g. European 400-kV or North American 735-kV power line) whose subconductors are insulated on 30-km segments. Back-to-back SMs, protection modules (PMs) and line-monitoring systems (LMOS) are hooked to the line phases on a dead-end tower instead of yoke plates every 60 km. The SM is electrically connected in series with each line phase and redirects the current in one or more sub-conductors. The SPL is intended to be used as an actuator for power line de-icing to raise the grid's resilience and as a measurement device to feed an STG. It is also intended to be used for power flow and stability control. To improve the reliability, cyber security, redundancy and communication delay of the STG, the mini-substation processors of phases A, B and C of the SMs are optically interconnected through double-path, wide-band channels. The processing power is distributed along the power line to raise the transmission grid control performance.

KEYWORDS

Bundled conductors, line impedance modulator, optical link, smart power line, FACTS, load flow control, power system stability, smart transmission grid, EMP, GMD, cyber security, grid resilience.

I. Introduction

Following the 1998 extreme ice storm in Québec, the author started to study and design technologies for grid de-icing in an aim to avoid future major blackouts and protect the grid against disastrous failure. The focus was on the development of a bundle controlled line (BCL) technology based on switching modules (SMs) installed on bundled-conductor transmission lines [1]-[2]. This BCL technology has evolved into a new conceptual distributed FACTS technology, the smart power line (SPL) [3].

An SPL is a conventional bundled power line (e.g. European 400-kV or North-American 735-kV power line) whose sub-conductors composing the phase bundle are insulated on 30-km segments. Back-to-back SMs, protection modules (PMs) and line monitoring systems (LMOS) are hooked to the line phases on a dead-end tower every 60 km (see Fig. 1). The SM is electrically connected in series with each line phase and redirects the current in one or more sub-conductors. It has no electrical reference with the other phases or ground and does not affect the properties of the mechanical line because it is not mechanically in series with the line.

The SPL is intended to be used for on-load power line de-icing (LDI) and galloping suppression by the joule effect. It can also be used for power flow control, stability control, inter-area and sub-synchronous oscillation damping with a line impedance modulator (LIM) and as a measurement device for line monitoring (LMOS) (e.g. phasor measurement unit, mechanical load monitoring and fault location) to feed a smart transmission grid. This technology is aimed at increasing line reliability and life expectancy. This basic BCL technology has a line impedance modulation range of 60% without any passive components [4].

* couture.pierre@ireq.ca

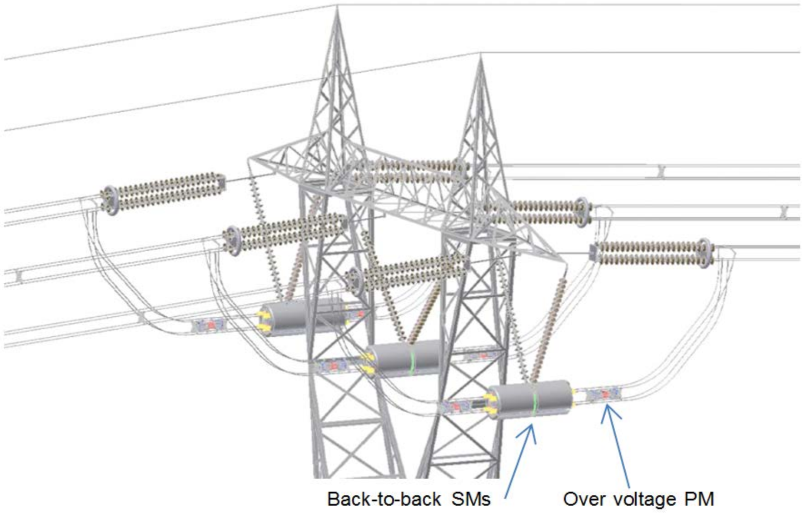

Figure 1: Back-to-back SMs and PMs anchored to a dead-end tower in place of yoke plates.

In principle, in cold regions and ice storm areas, the power line transmission-line capacity of single-, two- or multi-conductor bundled power lines could be raised [5]. This calls for the addition of one or more subconductors, SMs, insulated and instrumented yoke plates and insulated spacers. The de-icing function of the resulting SPL is expected to compensate for the additional conductor weights by rendering nil the most stressful scenarios of combined loads of ice and wind. This method avoids reinforcing the towers, insulators and tower foundations. The addition of extra subconductors reduces the power line impedance and increases the power line transmission capacity as well as reducing corona discharges.

The voltage supported by the SMs, yoke plates and spacers is a function of the length of the line segment. Each controlled line segment can typically be as long as 20–50 km. The length of a segment depends on the application and is limited by a) the open-switch voltage that the SM, spacers and yoke plates would have to withstand and b) the available space within the SM to hold these switches. For some applications, the length would be the result of trade-offs between the cost of the SM versus the voltage and the number of SMs. The voltages at the terminals of the open switches of an SM increase with the segment length and the line current intensity. These switch voltages are at their nominal value when all three switches of a bundle are open while the line current is at its nominal value. In the case of a 735-kV power line and a 30-km segment, the voltage at the switch terminals can reach 15 kV rms at a nominal power of 2000 MW.

The SPL can operate with any number of subconductors per bundle but, for the purposes of this paper, we will restrict our discussion to a 735-kV power line with four subconductors per bundle on 30-km segments. A three-phase line segment made of bundles of isolated subconductors together with SMs is referred to as a bundle-controlled line (BCL) segment. An SPL is made of many BCL segments [6].

The SPL can, in principle, be used for modifying the power flow through an electric transmission grid in static or dynamic mode. An auxiliary module with passive components could be connected in parallel with the switching module for some specific applications (Fig. 2).

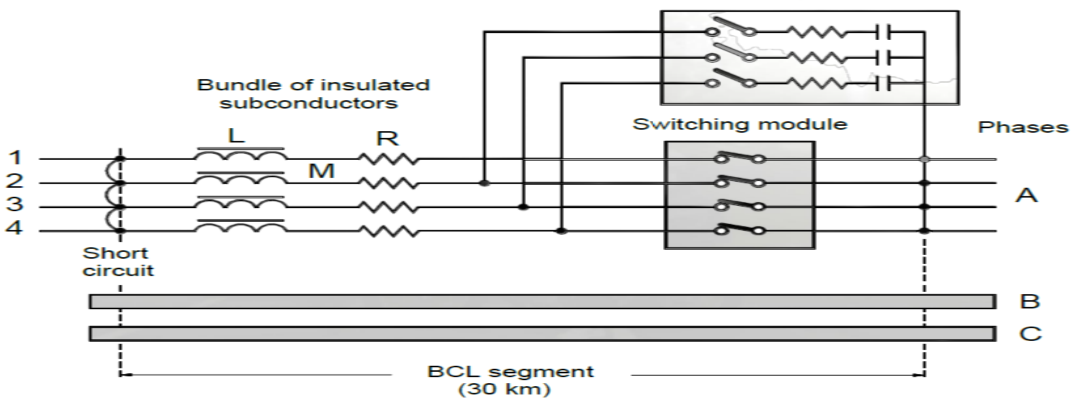

Figure 2: Schematic of a basic BCL segment.

The general concept of a smart grid was exposed by Amin and Wollenberg in 2005 [7]. The present paper introduced a new technological concept or architecture to make a smart transmission grid (STG) with SPLs. This concept uses a network of many SPLs with improved communications and distributes the computing power directly on the power lines. This architecture leads to an STG with, in principle, better reliability, resilience, cyber security, redundancy and response time than the original SPL architecture.

2. Smart power line characteristics and limitations

The SPL approach for de-icing and power flow control with this distributed FACTS device is used to minimize the equipment cost by exploiting the inherent properties of bundled transmission lines and to eliminate the footprint by anchoring small SMs to a limited number of transmission towers. Conversion of a bundled power line into a SPL requires dividing the power line in 20- to 50-km segments to satisfy electromagnetic laws and switching technology. The optimal mechanical configuration solution requires using back-to-back SMs and PM (lightning arrester module) anchored to a dead-end tower every 40-100 km facilitating SM installation and maintenance operations (Fig. 1).

Each SM is completely independent of the others and has its own processors, memories, current and voltage sensors, online power supply (capacitive and inductive), GPS and radio frequency (RF) wireless telecommunication systems with the Optical Ground Wire (OPGW). The SM controller includes processors, memory and an input/output bus. Combination of the three-phase SMs and PMs anchored on dead-end towers every 60 km represents a mini-substation. The mini-substation SMs of phases A, B and C communicate with each other via RF wireless communication devices. These devices allow the SMs to communicate with one another even though they operate at different potentials. The SM includes mechanical and/or electronic changeover switches, actuators or linear motors, sensors for current, tension, and position, and a transceiver to communicate with the sensors (e.g. strain gauges) located along the BCL segment associated with this SM.

For redundancy and continuity purposes, each subconductor of the SMs has two vacuum switches connected in parallel, the main switch and a bypass switch [8]. The bypass switches are used to cancel the main switches in case of failure or to return the BCL segment to its fundamental state with its full transit capacity in case of failure of the SM power supply or failure of the SM telecommunications system.

For SPL reliability purposes, each controller of the two back-to-back SMs must include three processors operating in parallel and connected to one another. Computations are performed simultaneously and in parallel within each processor and the processors compare their results among themselves. If one of the values computed by a processor is different from the values computed by the other two processors, the processor having computed the erroneous value is discarded to ensure that the computations of the controller are always reliable.

The controller, moreover, comprises a stand-by processor which is linked to each of the three aforementioned processors and is activated to substitute for the processor that has computed the erroneous value. The controller can include at least one or two additional processors for performing specific computations of the power line parameters (e.g. phasor measurement unit, fault locator). All processors are mounted on the same chip and interlinked.

Usually for de-icing and steady-state power flow management applications, the RF wireless telecommunication between SPL SMs and the OPGW to the control room is sufficient. For dynamic-stability control applications and to protect the transmission grid against electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs) from solar storms or ill-intentioned intrusions, a stronger communication link is needed.

More recently, three other distributed FACTS have been disclosed [9], the distributed static series compensator (DSSC) [10]-[13], the distributed power flow controller (DPFC) [14]-[15] and the distributed power flow controller based on an emitter turn-off light converter (DPFC-ETO) [16]-[17]. Their operation is different in many respects from that of an SPL.

Despite these differences, these three devices and the SPL share a common expectation, namely a low implementation cost due to the use of small, standard single-phase modules. Compared to the other three series-distributed FACTS devices, the application domain of the SPL technology can be very different. For instance, it has the capability to concentrate all the line current of a bundle into one subconductor at a time for de-icing by the joule effect, a function that is clearly not feasible with the other technologies.

To break the addiction to oil and fossil fuels in general, more renewable-energy sources such as wind and solar energies are now being connected to the grid while plug-in hybrid electric vehicles with an all-electric range sufficient to meet average daily needs are planned for deployment soon (IEEE-USA, 2009) [18]. This increased dependence on the grid means that the transmission-grid capacity and reliability must be improved. Following China's 2008 extreme ice-snowstorm disaster, it was recommended to increase grid efficiency, reliability and resilience [19]-[20]. More recently, the US government has emphasized the economic benefits of increasing electrical-grid resilience to face severe weather conditions [21].

3. STG requirements

In order to improve SPL grid capacity, reliability and resilience it would be highly desirable if SPL SMs could also perform locally some of the functions generally performed by the remote centralized control system. In order to achieve real-time grid control, it would be faster and more efficient if some of the mini-substation and grid computations were performed locally by the SMs rather than having to wait for instructions from the remote-control system. The amount of computations involved in the monitoring, management and control of a transmission grid is sizable. It would therefore be very advantageous to use the processing power of SMs for performing at least some of these computations and to exchange high-level information between SMs and the control room.

The electrical grid must be reliable and a portion of the control, monitoring and protection functions cannot be transferred from a centralized control system and distributed among several conventional conceptual SPL SMs. This is due to the RF communication signals which are affected by electromagnetic disturbances such as EMPs and GMDs and subject to ill-intentioned disturbances and intrusions. Also, the conceptual SPL SM controller does not have enough computing power to allow proper distribution of the control and protection of the grid. Furthermore, the RF communication bandwidth between phases A, B and C is too small to transmit large amounts of data quickly. Finally, the GPS, just like RF signals, can be affected by EMPs and GMDs.

In order to transfer some of the computing power of the electrical grid from the remote-control room to the SM controller, communications between SMs and the control room must be robust, especially against EMPs and GMDs, and compatible with cyber security.

4. STG Solution

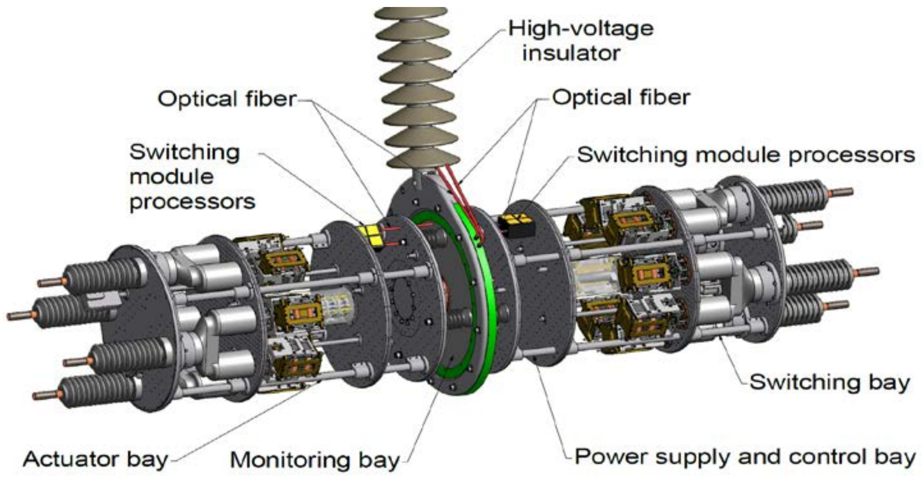

Figure 3: Schematic of optical-fiber path on single-phase STG back-to-back SMs (without the external shell).

To solve those SPL limitations and meet the STG computing power, reliability, cyber security and bandwidth requirements, we propose to use an SPL SM processor chip with two independent optical links in a back-to-back configuration [22].

The first optical fiber A1 is connected to the second SM processor of the two back-to-back SMs on the same phase, while the second A2 is connected through a double optical-fiber HV synthetic insulator to an optical router and to the control room via the OPGW (Figs. 3 and 4). The router is used to route optical signals from the back-to-back SMs to the other phase back-to-back SMs of the mini-substation or to the other mini-substations along the line through OPGW.

In Fig. 3, STG back-to-back SMs are shown with the protective cover removed for a better view of the components inside. The two back-to-back SMs share the same entry plate without having to use connecting rods between the SMs. Four subconductor feed-through bushings are located at the outer extremity of the first SM, each of them connected to one of the subconductors of the bundled phase line. Each feedthrough bushing of the SM is linked to a controllable switching device, in this case a vacuum interrupter located in a first compartment (the switching bay). Each vacuum interrupter is connected in turn to a controllable motor located in a second compartment (the actuator bay) to close or open the interrupter [23]. A third compartment (the power supply and control bay) houses a controller which is linked to the controllable switching devices. The power supply and control bay also include a GPS and a RF transceiver. The parameters measured by sensors (e.g. strain gauges) located along the BCL segment can be sent through the RF transceiver to the SM controller. In a fourth compartment (the monitoring bay) are located a current sensor and transformers of the SM power supplies.

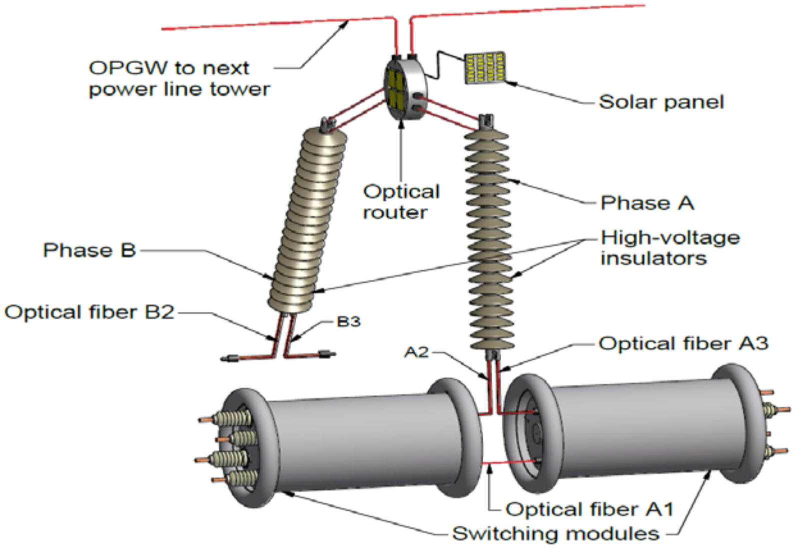

Figure 4: Mechanical components and optical link path schematic of STG mini-substation.

The second SM has the same configuration as the first. Both controllers, in this case consisting of many processors mounted on a single substrate, are provided with two optical ports. The first port of the first SM controller connects to the first port of the second SM via the first optical fiber A1.

The second optical port is for connection to an external system of the two back-to-back SMs. The second optical fiber A2 is connected to the second port of the first SM and a third optical fiber A3 is connected to the second port of the second SM. The second A2 and third A3 optical fibers exit the two back-to-back SMs through the same HV synthetic insulator chain and are connected to an optical router (Figs. 4 and 5). The controller with optical ports and the router could be built using a silicon photonics technology [24]-[25].The router can be composed of optical circuits or electro-optical circuits; it includes a power source which can be either a solar-based or a capacitive supply.

Each back-to-back SM of the three phases A, B, and C is optically linked to an optical router through two optical fibers. The first optical fibers B1 of phase B (second back-to-back SMs and phase C) are not shown in order to simplify Fig. 4.The back-to-back configuration is particularly interesting since it allows the line impedance to be increased smoothly by a factor of 1.64 without injecting zero-and negative-sequence currents higher than those of a standard transmission line into the power system [26].

As shown in Fig. 5, each controller is provided with input and output buses in addition to the optical ports, in order to receive and send information from/to other types of devices (not shown) such as sensors, switching actuators and the RF transceiver, for instance. Such devices are located in the SMs to provide the controller with information about the current, the voltage, the actuator positions or the ice load of the conductor. In this configuration of the system, the second A2 and third A3 optical fibers pass through the same insulator chain. However, in order to increase the redundancy, it may be preferable that these optical fibers pass through different insulator chains.

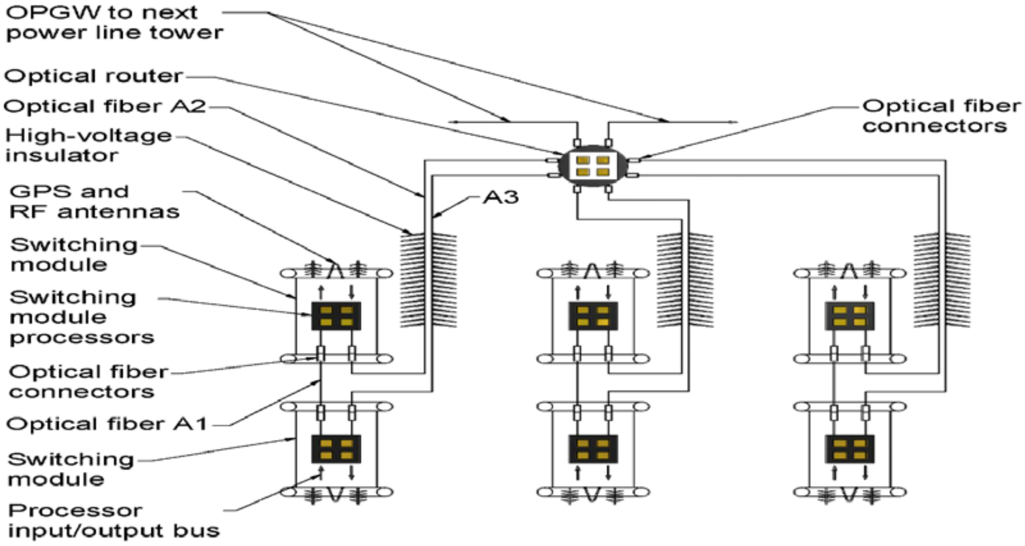

Figure 5: Schematic of the processors and router optical link of STG mini-substation.

Still referring to Fig. 5, the optical router allows interfacing the controllers of the pair of back-to-back SMs hooked on phase A to the other two back-to-back SMs connected to phases B and C, but also to the main optical fiber, which is ultimately connected to the next router of the power line or to a remote-control room. The main optical fiber is an optical link relayed from one router to the next, and generally located in the OPGW running along the power line segments (Fig. 6).

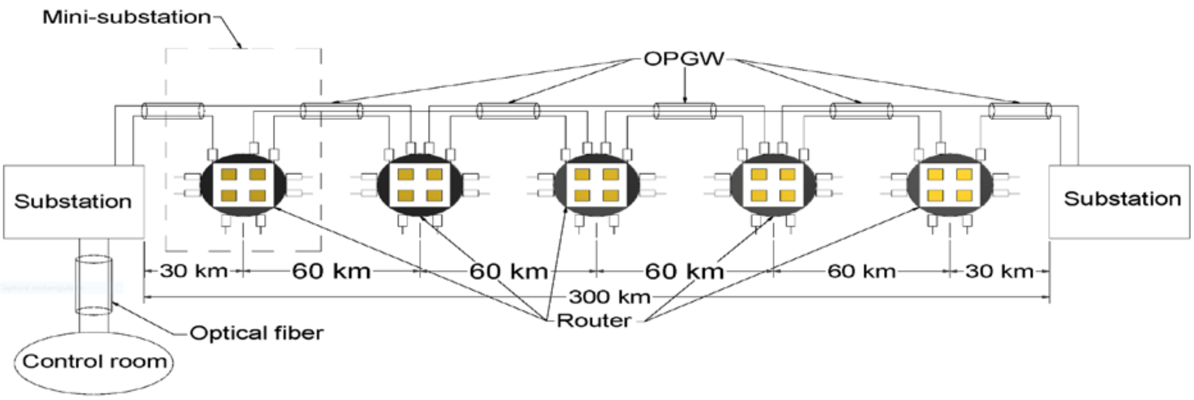

Figure 6: Schematic of router's optical link of STG mini-substations on 300-km power lines with OPGW.

Figure 6 shows a schematic of the optical link and routers of STG mini-substations on 300-km power lines with OPGW. The SM's processors are not shown in order to simplify the figure. Ultimately, the main optical fiber connects to a remote-control room which monitors and controls the operation of the high-voltage electrical grid. Naturally, the main optical fiber is not necessarily located in the ground wire.

As can be appreciated, the mini-substation controllers of all six SMs are able to send and receive the first and second optical signals via the router. With this configuration, the controller of a SM is always provided with two optical paths providing the system with increased redundancy and reliability.

Each one of the five routers forms part of its respective mini-substation, the three middle routers being associated with three pairs of SMs for phases A, B and C while the two outer routers are associated with the outer segments of the portion of the electrical power line between two substations. In this configuration of the distributed system, each of the three middle routers is provided with ten optical ports. Of these, three pairs (shown unconnected) are for connecting to the three back-to-back SMs hooked onto each phase line, as shown in Fig. 5. Two other ports connect with the adjacent routers of segments or with one of the substations via the router-to-router OPGW. Finally, the last two ports connect to the second adjacent router on the transmission line or to the substations via two other router-to-router optical fibers. The two routers at the extremity of the line are provided with only nine ports as they are directly adjacent to the substation. One of the substations is connected to a remote-control system.

As may be appreciated, such a configuration further improves the reliability and redundancy of the distributed system because there are always two optical paths to reach the SM controllers. For example, if the entire mini-substation system consisting of three back-to-back SMs and a router, located on an anchor tower, happened to fail, the failed BCL segment would automatically return to its fundamental state with its full transit capacity. The remaining systems on the power line can continue to function normally with reduced impedance modulation and the communication to the substations or to the remote-control system would not be affected by this failure.

5. STG Definition

An STG consists of a set of SPLs. The SPL SM processors of the three phases A, B and C of the same mini-substation are all optically connected among themselves and with those of the other mini-substations located along the transmission line and with the control room of the transmission system. This is done with an independent and redundant optical fiber network.

STG = ∑ SPL + Independent, Shielded and Redundant Synchronized Optical Fiber Network.

This STG architecture allows the distribution of control and protection functions of the grid along transmission lines by increasing the mini-substation computing power, reducing communication time and by increasing the redundancy in the computing and control processors, the monitoring systems and the communication systems. It also increases the system robustness to EMPs and GMDs and to undesired intrusions.

The STG architecture improves the resilience of the grid under extreme icing conditions by allowing power line de-icing. It also allows a) measurement of redundant synchro phasors distributed along the lines, b) protection of the lines, the power flow and control of the grid stability, and c) an increase in the transit capacity. Real-time surveillance of the lines and SMs allows databases of transmission system faults to be established.

Line surveillance implies a surveillance also of electrical events (flashover caused by switching impulses), mechanical events (e.g. galloping, wind vibrations), meteorological events (e.g. ice, lightning), and the SM environment with video camera and a mini-weather station.

Furthermore, this STG architecture offers a view, in real time, of the power flow in the system, the creation of databases of events experienced by the line and the electrical grid. From this data it will be possible to deduce a series of actions to execute, in real or delayed time, in order to ensure optimal maintenance of the transmission system. With the data obtained from all the SMs of the STG, the behavior and the reliability of the grid can be increased using appropriate software applications and expert systems.

6. Discussion

The STG enables the distribution of the needed data processing to control the grid and part of the protection of the transmission lines in mini-substations located along the lines. This new technology connects each SM with two optical fibers, one coming from a router and the other from the second SM located on the back of the first SM instead of a simple RF connection. This optical link can be a wideband channel (>10 GHz) with multi-channels of different wavelengths. This redundant optical link of silicon photonic processors enables the processors of the two back-to-back switching modules of each phase A, B and C of the same mini-substation to be grouped and to communicate with the others mini-substations with the aid of a silicon photonic optical router. The routers from the mini-substations of a same line are connected between themselves and with the control room of the grid with at least two optical fibers.

This STG architecture increases:

1. The redundancy and computing power of the processing system and power line control. Each SM includes three processors that carry out the processing of the task in parallel with a pending fourth processor ready to take over in case of malfunction. A certain number of processors can be added to carry out additional tasks. All these processors grouped with those of other phases of different potential act like a super processor. The back-up and additional processors can be shared.
2. For a corridor with two power lines and one OPGW, the redundancy and computing power of the processing system. This is achieved by optically connecting the processors, the back-up processors and the additional processors of a second power line located in the same corridor at different potentials and in the same mini- substations.
3. The robustness of the SPL and the STG to electromagnetic disturbances (EMP and GMD). Only the

signal sensors located along the 30-km segment are connected by an RF communication link to the corresponding SM. These signals are not critical to the operation or the protection of the transmission system.

4. The redundancy of the GPS receivers and transceivers for communication with the sensors located along the segment associated with the SM.
5. The robustness of the transmission system to potential disturbances in the GPS because a temporal reference signal is sent to each SM by optical fiber with an indicator of the path taken. This time reference is calibrated with a GPS for different paths.
6. The robustness of the transmission system to undesired intrusions by utilizing appropriate communication protocols and encryptions in a relatively secure environment of an isolated optical ground wire (OPGW) fiber network. It is easier to interfere with a wireless communication system than with an optical fiber communication system.
7. The robustness of the communication system by increasing the redundancy in the channels and the optical-fiber communication paths.

7. Conclusion

The introduction of two new components (optically coupled processor chips and the optical router based on silicon photonics) into the SPL grid concept improves the redundancy and resilience and produces a reliable STG compatible with cyber security. The new STG architecture resolves some of the drawbacks of the SPL grid concept by means of a distributed control grid where the basic computations necessary for system control can be executed at the level of the SMs distributed on the phases along the line. After an initial processing, the computation results, with the appropriate software, are shared between the SMs and the control room, thus reducing both the quantity of information that needs to be shared and the communication time while maintaining a fast, safe, and reliable response time.

ACKNOWLEDGMENT

The author acknowledges the support of Michel Belley of IREQ for the drawings in this publication.

BIBLIOGRAPHY

[1] P. Couture, “Module de dégivrage sous charge pour lignes de transport avec des phases à multiconducteurs”, 67e Congrès de l'ACFAS - Colloque C-213, May 12, 1999.
[2] P. Couture, “Switching apparatus and method for a segment of an electric power line,” U.S. Patent 6 396 172 B1, May 28, 2002.
[3] P. Couture, “Smart power line and photonic de-icer concepts for transmission-line capacity and reliability improvement,” Cold Reg. Sci. Technol. 65 (2011), January, pp.13-22.
[4] P. Couture, “Switching modules for the extraction/injection of power (without ground or phase reference) from a bundled HV line,” *IEEE Trans. Power Delivery*, vol. 19, No3, pp. 1259–1266, July 2004.
[5] P. Couture, “Method for increasing high-voltage power line transmission capacity in a region subject to freezing rain,” Published patent application under Canadian Patent 2441241, Sept. 10, 2003.
[6] P. Couture, J. Brochu, G. Sybille, P. Giroux, A. O. Barry, “Power Flow and Stability Control Using an Integrated HV Bundle-Controlled Line-Impedance Modulator,” *IEEE Trans. Power Del.*, Vol. 25, No. 4, pp. , October 2010.
[7] S. M. Amin, B. F. Wollenberg, "Toward a smart grid: Power delivery for the 21st century," IEEE Power and Energy Magazine 3 (5): Sept./Oct. 2005.
[8] P. Couture and J. Leduc, “Switching apparatus and method for varying an impedance of a phase line of a segment on an electrical power line,” U.S. Patent 7 639 460, Dec. 29, 2009.
[9] S. R. Gaigowal and M. M. Renge, “Some studies of distributed series FACTS controller to control active power flow through transmission line,” International Conference on Power, Energy and Control (ICPEC), Feb. 2013.
[10] D. M. Divan, W. E. Brumsickle, R. S. Schneider, B. Kranz, R. W. Gascoigne, D. T. Bradshaw, M. R. Ingram and I. S. Grant, “A distributed static series compensator system for realizing active power flow control on existing power lines,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 642-649, Jan. 2007.
[11] H. Johal, D. Divan, “Current Limiting Conductors: A distributed approach for increasing T&D system capacity and enhancing reliability” IEEE PES, pp.1127-1133, May 2006.
[12] S. Golshannavaz, M. Mokhtari, M. Khalilian and D. Nazarpour, “Transient stability enhancement in power system with distributed static series compensator (DSSC),” Iranian Conference on Electrical Engineering (ICEE), May 2011.

[13] A. Rathi, A. Sadda, L. Nebhnani and V. M. Maheshwari, "Loss minimization with D-FACTS devices using sensitivity based technique," India International Conference on Power Electronics (IICPE), Dec. 2012.
[14] Z. Yuan, S. W. H. de Haan, J. B. Ferreira and D. Cvoric, "A FACTS device: Distributed power-flow controller (DPFC)," IEEE Trans. Power Elect., vol. 25, no. 10, pp. 2564-2572, Oct. 2010.
[15] A. Jamshidi, A. M. Barakati and M. M. Ghahderijani, "Power quality improvement and mitigation case study using distributed power flow controller," International Symposium on Industrial Electronics (ISIE), May 2012.
[16] W. Song, A. Q. Huang and A Bhattacharya, "Distributed power flow controller design based-on ETO-kight converter," Applied Power Electronics Conference and Exposition (APEC), Feb. 2008.
[17] A.Huang, Y. Liu, Q. Chen, J. Li, W. Song, "Emitter turn-off (ETO) thyristor, ETO light converter and their grid applications," Power & Energy Society General Meeting (PES), July 2009.
[18] IEEE-USA, 2009. Policy Position Statement, "National Energy Policy Recommendations," January.
[19] Q. Ye "Building resilient power grids from integrated risk governance perspective: A lesson learned from china's 2008 Ice-Snow Storm disaster," Eur. Phys. J. Special Topics 223, 2439–2449 July2014.
[20] X. Jiang, Y. Wang, L. Shu, Z. Zhang, Q. Hu, Q. Wang, "Control scheme of the de-icing method by the transferred current of bundled conductors and its key parameters," IET Gener. Transm. Distrib. 2015, Vol. 9, Iss. 15, pp. 2198–2205.
[21] Executive Office of the President, "Economic benefits of increasing electric grid resilience to weather outages," August 2013.
[22] P. Couture, "Switching apparatus, control system and method for varying an impedance of a phase line," Patent pending, PCT/CA2011/00850, July 22, 2011.
[23] Francoeur, B., Couture P., 2018 Actionneur électromagnétique bistable, PCT/CA2018/051391 "Patent pending" Nov. 5.
[24] R. Soref, "The Past, Present, and Future of Silicon Photonics," IEEE J Sel Top Quantum Electronics, November/December 2006; 12; 1678-87.
[25] S. Fathpour "Emerging heterogeneous integrated photonic platforms on silicon," Nanophotonics, 2015; 4: pp.143-164.
[26] J. Brochu and P. Couture, "Load flow modeling of the integrated bundle-controlled line impedance modulator," *IEEE Trans. Power Delivery*, Vol 30, No. 2, 957-966, April 2015.

BIOGRAPHY

Dr. Pierre Couture received his Ph.D. in Plasma Physics from INRS-Énergie, Université du Québec in 1979. He joined the Hydro-Québec Research Institute (IREQ) in 1978 to work on the design of the Varennes Tokamak. From 1983 to 1985 he worked at the Princeton Plasma Physics Laboratory on H mode on PDX and High Beta Tokamak plasma on PBX. On his return to Hydro-Québec, he started research on the biasing of Tokamak plasma. In 1989, he took charge of the operation of the Varennes Tokamak and in 1990, after commissioning the poloidal divertor, he succeeded in making the first biasing experiment of divertor plasma. He left the program in 1991 to head the M4 research team to develop a series hybrid wheel-motor plug-in power train for electric vehicles. In 1996, he joined the Power Lines Department to study lightning phenomena and in 1998, following the ice storm in Québec, he conceived and developed a de-icing technology. He is now collaborating on the conception and development of a continuous fast-forward annealing process CFF-RTA for an amorphous-metal ribbon and an amorphous-metal rolled-up-core distribution transformer. His main working activities consist in conceiving and developing the Smart Power-Line (SPL) concept and the Smart Transmission Grid (STG) to improve the transmission network transit capacity and its reliability.