A Review Article of SAF based Transmission System

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Abstract— Line commuted converter user in SAF (Shunt Active Filter) transmission systems inject harmonics into their associated AC and DC systems. A conventional approach to filter these harmonics is to use passive filters on both AC and DC sides of the converter. Apart from their technical problems, harmonic filters constitute a considerable part of the volume and cost of present DC terminal stations. Another possible alternative of harmonic suppression is to increase the number of pulses of AC-DC converters by transformer phase-shifting techniques, but the resulting complicated circuitry together with its problems of insulation produce significant technical and economical disadvantages. This Paper presents an overview of classical SAF transmission system. It also provides a brief historical development of the technology and state of art in the field of SAF transmission system. Based on outcome of literature survey, broad research goals are identified.

Key words: SAF (Shunt Active Filter), Transmission System

I. Introduction

At the beginning of the 1970s, once with the first oil crisis, the interest on the renewable energy sources had emerged. Thus, the wind power industry, one of the most powerful and successful industry in the last four decades, had appeared. Since then, the development in this industry is continuous and at a high rate.

The fast growth in everything which means wind power is possible due to several facts, such as: reticence in using fossil fuels (from both environmental issues and high prices point of view) and development of power electronics etc.

According to a survey, the wind energy sector continued its market growth in the EU at an increased rate of 23% compared to year 2008 installations. It is also observed that most of the installations are happening in offshore as compared to onshore. Furthermore, it is observed that the annual installations in The European Union have increased steadily during the last fifteen years from only 472 MW wind power installed in 1994 to more than 10 GW in 2009.

As it is well known, the offshore wind power is very important to the Europe future, and so, the present trend in the wind power industry is to develop its offshore sector. The offshore wind industry will overtake the onshore wind mainly due to two aspects. Firstly, the "offshore wind" is characterized by average annual wind speeds bigger than the "onshore wind" and secondly, the onshore sites which are available to be used for wind farms will slowly decreasing. Thus, in the next years, the trend in the wind power industry will be to move from onshore to offshore.

Until now, the offshore sites which were preferred to be used for wind farms were the ones close to the shore and with relative small water depths. But, there are several aspects which burden the use of these sites: the near-shore area is often used for maritime traffic, recreational activities and/or fishing. Moreover the placement of a wind farm close to the shore will have a bad impact from the noise disturbances and visibility point of view.

Based on these presented facts, one of the trends concerning offshore wind farms is to increase the distance from the wind farm to the shore.

A consequence of this trend is that the generated power in offshore wind farms has to be transported over very long distances to make a connection with the main supply grid. The solution which overcomes this problem is the use of the High Voltage Direct Current (SAF) transmission systems which are more feasible and also more competitive than the traditional High Voltage Alternative Current (HVAC) transmission systems. One of the most important advantages of SAF transmission technology over the HVAC transmission technology is that the first one is suitable for long distances (even 500 - 600 km) with minimal losses. The second big advantage concerns the Right-of-Way (RoW); often it is easier to obtain RoW permission for submarine DC cables because of the reduced environmental impacts. Furthermore, in the case of VSC-based SAF transmission system, the voltage source converter substations can be used to stabilize the AC networks in their connection points and also it can be used to provide black start and may support the system recovery in case of a failure.

II. Overview of SAF transmission system

The SAF transmission system is a high power electronics technology used in electric power systems mainly due to its capability of transmitting large amount of power over long distances. Overhead lines or underground/submarine cables can be used as transmission path. The High Voltage Direct Current (SAF) technology was used for the first time in 1954 in the under-sea cable interconnection between the island of Gotland (Sweden) and Sweden. For this transmission, thyristors with a rating of 50 kV and 100 A were used. From its beginnings until the mid1970s, the SAF transmissions were based on mercury arc valves. After that, for the next 25 years, line commutated converters - using thyristors as based component - were used in the SAF transmission systems. Once with the development of the high power switching devices and their availability at low prices, the LCCs were replaced by the self-commutated converters and now the voltage source converters are more and more used for SAF transmissions.

III. Comparison of HVAC & SAF transmissions

The SAF transmissions can be compared with the HVAC transmission basically from two points of view: from the transmission costs point of view and from the technical point of view respectively. Analyzing the two systems regarding the transmission costs, the next advantages of SAF transmission systems over the HVAC transmission systems can be found:

considering similar insulating requirements for peak voltage levels, a DC line/cable will carry the same amount of power with two conductors as an AC line/cable with three conductors; thus, for the same power level, an SAF transmission system will require smaller Right-of-Way, simpler towers and also the conductor and insulator costs will be reduced, in comparison with a classical HVAC transmission;

The power transmission losses (conductor losses) are reduced by about two-thirds when the DC option is used instead of the AC one;

Furthermore, when a SAF transmission is used, the absence of the skin effect can be noticed and also the dielectric and corona losses are kept at low level, thus the efficiency of the transmission is increased;

However, the disadvantage of the SAF transmissions regarding the costs comes from use of the converters and filters.

As a conclusion it can be said that the HVAC transmissions are more economical than SAF transmissions when used for small distances. Once the breakeven distance is reached the DC alternative becomes more economical fact which may be observed.

In the case of the overhead lines the breakeven distance can vary between 400 to 700 km, depending on the per unit line costs while, if a cable system is used the breakeven distance vary between 25 and 50 km. The typical breakeven distance for overhead lines is 500 km.

Analyzing the two transmission systems, from the technical point of view, the SAF transmissions overcome some of the problems which are usually associated with the AC transmissions. Thus, the stability limits are overcome when an SAF transmission is used due to the fact that the power carrying ability of DC lines is not affected by the transmission distance. In the case of the HVAC transmission the power transfer in the AC lines is dependent on the phase angle which increases with the distance and thus the power transfer is limited.

The second problem which is solved by using the DC transmission instead of the AC transmission is the line charging. In the case of an HVAC transmission, line compensation (using STATCOMs, SVCs etc) is used in order to solve the line charging issue, while in the case of DC lines such compensation is not required. Due to this issue, in the case of HVAC transmission the breakeven distance is reduced to 50 km. Moreover, asynchronous interconnection of two AC power systems can be realized using the SAF technology.

On the other hand the early use of SAF transmission systems was limited due to several factors such as: high cost of converters, generation of harmonics, complexity of controls, inability to use transformer to alter voltage levels etc. However, over the time many of these above presented issues were solved except the inability to use transformer to alter voltage levels.

As a conclusion to this comparison it can be said that the SAF transmission technology is attractive and advantageous for long power transmissions, bulk power delivery, long submarine power crossing and also asynchronous interconnections.

IV. APPLICATIONS OF SAF TRANSMISSIONS

The SAF transmissions are basically used in one of the following four applications:

A. Underground or Underwater Cables

In the case of long cable connections over the breakeven distance of about 40-50 km, DC cable transmission system has a marked advantage over AC cable connections. The recent development of Voltage Source Converters (VSC) and the use of rugged polymer DC cables, with the so-called “SAF Light” option, are being increasingly considered. An example of this type of application is the 180 MW Direct link connections (2000) in Australia.

B. Long Distance Bulk Power Transmission

Bulk power transmission over long distances is an application ideally suited for DC transmission and is more economical than AC transmission whenever the breakeven distance is exceeded. Examples of this type of application abound from the earlier Pacific Intertie to the recent links in China and India. The breakeven distance is being effectively decreased with the reduced costs of new compact converter stations possible due to the recent advances in power electronics.

V. OVERVIEW OF VSC BASED SAF SYSTEM

A SAF system requires an electronic converter for its ability of converting electrical energy from ac-dc or vice versa. There are basically two configuration types of three-phase converters possible for this conversion process (Figure 5):

– Current Source Converter (CSC), and
– Voltage Source Converter (VSC).

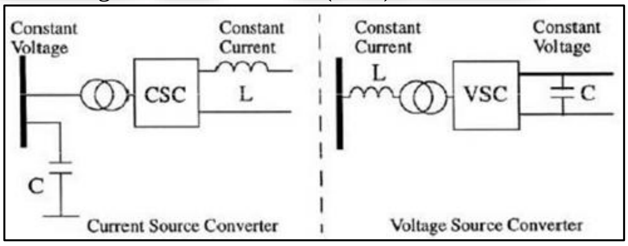

Fig. 5: Converters of the CSC and VSC types

During the period (about) 1950-1990s, SAF systems used the CSC configuration almost exclusively. The traditional CSC utilized the mercury-arc valve from the early 1950s to the mid-1970s, and thereafter, the thyristors valve as its fundamental switching device.

From about 1990 onwards, the alternative VSC became economically viable due to the availability of new self-commutating high-power switches (such as GTOs and IGBTs) and the computing power of DSPs to generate the appropriate firing patterns.

Modern SAF transmission systems can utilize either the traditional Current Source Converter (CSC) or the Voltage Source Converter (VSC) as the basic conversion workhorse. The two converters are actually duals of one another. However, the choice of which option is selected for a particular project is based upon economic and other factors. A comparison of the characteristics of the two converter types is made in Table 1-1. However, at present VSC are still limited to below 250 MW capacity due to commercial and practical limitations of the electronic switches.

	Converter Type	
	CSC	VSC
On AC side	– Acts As a constant voltage source – Requires a capacitor as its energy storing device – Requires large ac filters for harmonic elimination – Requires reactive power supply for power factor correction	– Acts as a constant current source – Requires an inductor as its energy storing device – Requires only a small ac filter for higher harmonic elimination – Reactive power supply is not required as converter can operate in any quadrant
On DC side	– Acts as constant current source – Requires an inductor as its energy storing device – Requires dc filter – Provides inherent fault control limiting feature	– Acts as a constant voltage source – Requires a capacitor as its energy storing device – Energy storage capacitor provides dc filtering capability at no extra cost – Problematic for dc line side faults since the changed capacitor will discharge into the fault
Switches	– Line commutated or force commutated with a series capacitor – Switching occurs at line frequency. i.e., only single pulsing per cycle – Lower switching losses	– Self-commutated – Switching occurs at high – Frequency. i.e., multiple – pulsing within one cycle – Higher switching losses
Rating range	– 0-550 MW per converter – Upto 600 kV	– 0-200 MW per converter – Upto 100 kV

Table 1: Comparison between CSC and VSC

VI. Advantages & Applications for VSC-based SAF

By analyzing the operation of both classic SAF technology and VSC-based SAF technology, the main difference between these two technologies can be highlighted: the controllability. Thus, the controllability in the case of VSC-based SAF technology is higher compared with the one of the earlier developed technology. Thereby, if VSCs are used instead of line-commutated CSCs several advantages can be stated, some of them being presented below:

VSC converter technology provides rapid and independent control of active and reactive power without needing extra compensating equipment; the reactive power can be controlled at both terminals independently of the DC transmission voltage level;

The commutation failures due to disturbances in the AC network can be reduced or even avoided if VSC-SAF technology is used;

The VSC-SAF system can be connected to a "weak" AC network or to a network where no generation source is available (the VSC can work independently of any AC source), so the short circuit level is low;

Self (forced) commutation with voltage source converters permits black start, which means that the VSC is used to synthesize a balanced set of three phase voltages as a virtual synchronous generator;

Due to its modular, compact and standardized construction, the converter can be easily and rapidly installed/commissioned at the desired site;

In comparison with the classic SAF transmission, the VSCs don not have any reactive power demand and moreover, they can control their reactive power to regulate the AC system voltage like a generator.

However, the VSC-based SAF technology has some drawbacks, which include potentially high power losses and high cost (caused by the converter stations) compared with traditional SAF technology.

VII. Conclusion

The SAF transmission technology can be realized by using current source converters (CSCs) commutated thyristor switches, known as traditional SAF or classic SAF, or by using voltage source converters (VSC-based SAF). Due to the rapid development of power electronic devices with turn-off capability and of DSPs, which are generating the appropriate offering patterns, the VSC are getting more and more attractive for SAF transmission.

Usually, the VSCs are using insulated gate bipolar transistor (IGBT) valves and pulse width modulation (PWM) for creating the desired voltage wave form. On the market, mainly two manufacture refer to the technology of DC transmission using VSC; these are: ABB under the name SAF Light R, with a power rating from tenths of megawatts up to over 1000 MW, and the second manufacturer is Siemens under the name SAF Plus ("Plus" - Power Link Universal Systems).

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