SOLID-STATE TRANSFORMERS

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ABSTRACT

Solid State Transformer (SST) has been regarded as one of the most emerging technologies in the power distribution system. It has the advantages of low volume, low weight, fault isolation, and potential additional functions, such as voltage regulation, reactive power compensation, and etc. However, the involvement of large number of power devices makes the control of SST a challenge. In addition, the high voltage and high power hardware design of the SST is not easy, certain design methodology needs to be developed. This paper considers the solid-state transformer concept as a viable alternative to the line frequency transformer in distribution circuits.

Keyword: - *Solid state transformers ,Line frequency Transformers*

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1. INTRODUCTION

Power generation, transmission, and distribution are the three main constituents of the modern power system, in which the transformer plays a most critical role. Transformers enable high efficiency and long distance power transmission by boosting the voltage to a higher one in the generation side with the so called power transformer. In the distribution system side, this high voltage is stepped down for industrial, commercial, and residential use with the so called distribution transformer.

The distribution transformer provides final voltage transformation to the end users in the distribution system, which usually with voltage level less than 34.5kV at high voltage side. At the low voltage side, 120/240V split single phase system and 480V three phase systems are usually adopted in the US.

2.PROBLEMS IN CONVENTIONAL DISTRIBUTION TRANSFORMER

The traditional line frequency transformer (LFT) provides a cheap and very efficient method for voltage level transformation and isolation. However, this direct transformation also introduces unwanted characteristics into the modern power grid, among which are the following:

1) The output voltage is a direct representation of the input. Any unwanted characteristics from the input, such as voltage dips or frequency variations, will be represented on the output.

2) The output current will likewise influence the input current. In a practical distribution environment the input current will be a reflection of the sum of the connected output currents. The presence of harmonics on the load currents will manifest themselves in the input current. For single phase residential customers odd harmonics especially the 3rd, 5th and 7th are notably present with values in excess of 15 % of the fundamental. As

with the total load the harmonics are rarely balanced among the three phases. With delta connected primary transformers the 3rd harmonic circulates in the primary winding and does not propagate to the network, but it does add to the primary winding losses.

3) In general, transformers are designed for maximum efficiency at near to full load. This results in a high standing loss, or a loss under no load conditions. In a distribution environment a transformer operates on average at about 30 % load.

4) All LFTs suffer from non-perfect voltage regulation. In general, the voltage regulation of a LFT is inversely proportional to the power rating of the transformer. At distribution level the transformers are generally small and the voltage regulation is not very good.

3.THE SOLID STATE TRANSFORMER CONCEPT

Recently, together with other technological advancements, power electronics is being seriously considered as one of the advantageous technologies that could empower future smart grids, doing so at all levels of electrical power systems. Power electronics is one of the key enabling technologies in electrical engineering nowadays. This is not entirely new, as high power converters played an increasing role in both distribution and transmission power systems over the past decades, for instance, in high voltage direct current (HVDC) transmission systems and flexible ac transmission system (FACTs) devices, such as static Var compensator (SVC), static synchronous compensator (STATCOM), unified power flow controller (UPFC), and others [7]. Another portion of high power converters have found increasing number of applications in renewable energy systems, especially in the case of large penetration of renewable resources, such as solar and wind.

The SST is a power electronic device that replaces the traditional 50/60 Hz power transformer by means of high frequency transformer isolated AC-AC conversion technique, which is represented in Figure 1-3. The basic operation of the SST is firstly to change the 50/60 Hz AC voltage to a high frequency one (normally in the range of several to tens of kilohertz), then this high frequency voltage is stepped up/down by a high frequency transformer with significantly decreased volume and weight, and finally shaped back into the desired 50/60 Hz voltage to feed the load. In this sense, the first advantage that the SST may offer is its reduced volume and weight compared with traditional transformers.

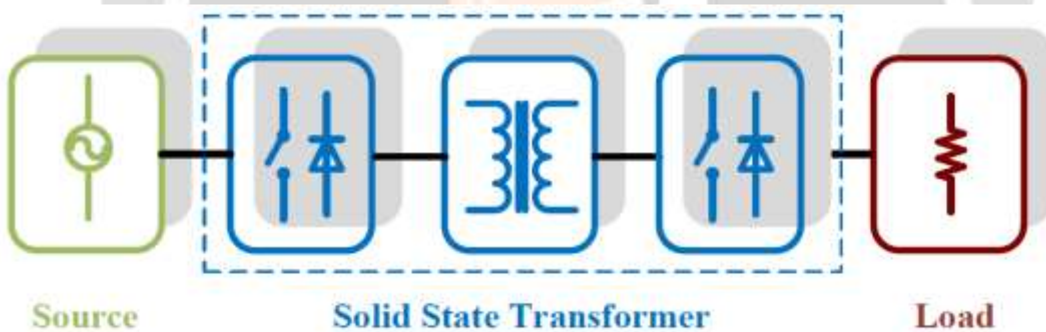

Fig 1 Concept of SST

It is further seen from the configuration of the SST that some other potential functionalities that are not owned by the traditional transformer may be obtained. On one hand, the involvement of the solid state devices and circuits make the voltage and current regulation a possibility by recalling the wide application of FACTs devices. This brings the promising advantages such as the power flow control, voltage sag compensation, fault current limitation, and etc, which are not possible for traditional transformers. On the other hand, voltage source converters (VSI) that may be applied in the low voltage side converter can possibly support a regulated low voltage DC bus, which can be connected with the DC microgrid, and thus enables the new microgrid architecture.

4.THE BENEFITS OF THE SST IN TERMS OF EXISTING PROBLEMS

The SST concept can address some of the problems experienced in distribution systems. In a direct comparison with the LFT drawbacks, as mentioned in the introduction, the SST addresses all the problem areas.

4.1. Power quality

The SST concept will improve power quality. Although the major improvement will benefit the costumers connected to the SST, the concept will also marginally improve the power quality of other users on the same network.

The power electronic converters on both sides of the isolation barrier, see Fig. 1, effectively separate the input voltage shape from the output voltage shape. This separation brings immediate benefits to the consumer connected to the low voltage side of the SST. Some of the more important advantages include:

1. The SST operates with an intermediate DC energy storage capacitor from where the output voltage is created. The voltage of the DC capacitor can be regulated by the front end converters through a wide range of input voltages. Therefore the output voltage will be immune from input voltage sags and dips within a designed band.

2. The output inverter operates with an output voltage control loop, implying that the output voltage will be regulated throughout the load range. This results in a near perfect voltage regulation.

3. The output voltage will also be pure sinusoidal and free of power frequency harmonics, regardless of input voltage shape.

4.2. Single Wire Earth Return Systems

Single wire earth return (SWER) systems are used in many countries, such as South Africa, Australia and New Zealand to electrify sparsely populated areas. SWER systems are generally an economic choice for feeders with load densities lower than 0.5 kVA/km. However, the system has several inherent disadvantages such as: the imbalance of load currents on the primary distribution line, inability to provide three phase voltages at point of use and voltage regulation.

The charging currents of a SWER system can be as high as 0.025 A/km for a 12.7 kV system. This high reactive current component coupled with a relatively small load current result in a leading power factor. As a result, the load voltage is very dependent on the load current. To provide better voltage regulation, SWER distribution systems are often fitted with a voltage regulator.

The SST concept will benefit distributions systems utilising SWER technology in that:

1) The SST can deliver rated voltage for a wide range of input voltages, resulting in a good overall system load regulation.
2) Using an SST to branch from the main feeder the SWER system would reflect a balanced three phase load to the utility, unlike the single phase load reflection in traditional systems.
3) Using a SST system with an available MV DC link, the power could be transmitted in DC. This not only eliminates the charging current and associated losses but also increases the power capability of the line for a certain conductor size and insulation capability.

4.3Protection

As part of normal operation the different controllers of the SST measure all the relevant operational parameters, such as the input and output current and voltage. Using this information the controllers have control over parameters such as the output voltage magnitude. Through the implicit control of the SST the concept will bring the following advantages to the distribution protection system:

1) If one of the outputs experience a line to ground short or another fault, the inverter can continue to supply power to the other two phases. The SST can relay information of the fault to the utility should maintenance be necessary. The inverter can also monitor the phase through active impedance measurement techniques to determine if the fault is still present and can reinstate power delivery to the faulty phase should the fault clear.

2) The SST acts as a barrier to fault currents. Even in the event of a full three phase fault on the LV side, the fault will not propagate back to the MV side. The network would not see a short circuit, as the SST simply decreases the output voltage to limit the fault current on the LV side, and hence limits the power flow through the SST. The network will however be informed of the fault through the communication interface.

5.POSSIBLE FUTURE BENEFITS OF THE SST

The SST concept could also offer a number of options to the distribution grid.

5.1 Integration with other systems

The LV DC link in the SST topology provides a good and readily accessible integration point for renewable energy systems into the distribution grid. A unidirectional converter could be used when the load demand is much bigger than the renewable energy generation capabilities. Where the peak generation capabilities exceed the load demand during certain periods, the excess power could be fed back into the grid by using a bidirectional converter. The low voltage AC can also be generated at any specific frequency and phase displacement. This allows the system to generate, for example, 60 Hz from a 50 Hz host system, or to interconnect systems with different phase displacements.

5.2. DC as a Means of Power Delivery

The SST concept is ideally suited to extend the use of DC, both in MV and LV applications. The difficulty in interrupting a DC feeder under fault conditions is often cited as a major hurdle in the acceptance of DC distribution in MV applications. The use of the power electronic interface (SST) to generate the DC is a means of controlling the system and interrupting fault currents.

DC power can also be made available on the LV side. Most modern household appliances make use of DC internally and would be able to operate from a 220 V DC supply. However, it is difficult to conceive that the future residential supply will change from AC to DC.

6.BARRIERS TO UNIVERSAL ACCEPTANCE

The power system community are used to the unique characteristics of the LFT. Many standards and preferred practices have been developed and accepted to allow for a robust and reliable system. The barriers to universal acceptance of the SST are as follows :

6.1. Cost

The cost of the LFT is much less than the cost of a comparable SST. The SST cost is mainly driven by semiconductor cost. The cost breakdown between, firstly, semiconductors and, secondly, other elements such as heat sinks, PC boards and passive components, would roughly be equal.The cost of the control circuitry, in comparison with the power components, is large. Further development of the concept could result in the development and use of ASICs (Application Specific Integrated Circuits) reducing the cost of the control circuitry.

Although the first generation SST prototypes will be very costly to manufacture, it is reasonable to expect that the costs will follow a downward trend in future. Not only will the net cost of power semiconductors decrease and the cost of control circuitry decrease through integration, but continued industrialisation will force the manufacturing costs down

6.2. Reliability

LFT transformers are in general very reliable. Most applications see the LFT in use exposed to the elements and operational in very harsh environments without requiring periodic maintenance.

Given the complex nature of the SST, the system is unlikely to be as reliable as the LFT. However, the total system reliability can be improved significantly.

6.3. Efficiency

The efficiency of a 80 kVA, 11 kV / 400 V LFT is in the region of 97 % (according to [2] the efficiency for a 30 kVA LFT must be > 97:3 % to qualify for NEMA class 1 efficiency level rating), while the efficiency of a corresponding SST will be somewhat lower .However, a straight comparison of the efficiencies is slightly misleading.

The losses in a LFT can be separated into two broad categories, namely core and winding losses. The nature of the losses are such that core losses are a function of the applied voltage on the primary winding while winding losses are determined by the power delivered. Therefore the core losses are often termed standing losses. The point of maximum efficiency of the LFT is roughly where the core losses and the winding losses are equal. Often the LFT is designed for maximum efficiency at full load, although according to new standard practices the point of maximum efficiency should be at 50 %

7.APPLICATION OF SST IN DISTRIBUTION SYSTEM

a. The SST has found its application in traction systems, where the SST can effectively replace the traditional transformer and power converters due to its configuration and voltage regulation capability. In addition, the SST can also be potentially integrated with energy storage devices when its DC link is available.

b. The SST may also provide VAr compensation depending on the topology adopted. The SST may also take the responsibility of harmonic current filtering, while the capability of it depends greatly on the bandwidth of its controller, which is in turn governed by the switching frequency of the SST

c. The SST has also been proposed as an energy router to integrate smart grid applications The basic idea is to utilize the low voltage DC link as the common bus to connect renewable energy

d. Unlike the passive power transformer, SST embedded with certain control functions may also enact fault isolation and limitation.

8.CONCLUSION

Although the LFT is in global use, many of its characteristics are unwanted in the modern distribution grid. This article discussed the benefits the SST concept could bring to the grid, most notably in terms of power quality. The SST concept also brings control and communication advantages to the grid. Although recent advancements in power semiconductor technology allow for renewed interest in the SST concept, In this article some of the drawbacks of the SST were highlighted. Solid state power electronics is becoming one of the most important enabling technologies for electric power transmission and distribution. However, since the utilization of power converters in transmission and distribution is still relatively low, the electric power grid remains one of the next major frontiers where to introduce large scale power electronics technology. However, with advances in power semiconductors and with each prototype the SST concept will mature.

9. REFERENCES

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