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Solid state transformer

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Abstract : *The conventional transformer in power infrastructure should be capable of meeting the demand for the load. The conventional transformer is structured and designed to handle high power. Also, the overload capacity of conventional transformers depends on the highest temperature and short-term overload. This paper represents the construction and working of the solid-state transformer which consists of AC to DC and DC to AC conversion which has low overload capability as compared to conventional transformers. Solid-state transformer finding applications in Solar and wind power generation electric vehicle battery management systems because of high-frequency operation, which is not possible in case of conventional transformers also smart transformer, provides flexible control of electric power distribution.*

Keywords - *AC to DC converter, Conventional transformer, DC to AC converter, High-frequency magnetics, Solid state transformer*

I. INTRODUCTION

The power infrastructure should be capable of the meeting the load demand but the non-conventional energy resources such as solar, wind and new loads such as electric vehicles challenge grid management and load dispatching activities. This new type of the loads creates problems such as phase's imbalance, power quality issues, and transformer overload. The conventional transformers are designed for handling higher power than the nominal one. Their overload capability depends on the highest temperature (hot spot), and short-term overload is permitted for a few hours per day. To make the power system, it is very important to make very sensitive to demand it will not only meet the need of present but also saves energy with improving the power quality. Among several scenarios, the smart transformer represents a solution for simultaneously managing low and medium voltage grids, providing ancillary services to the distribution grid. However, unlike conventional transformers, the smart transformer has a very limited overload capability, because the junction temperature which must always be below its maximum limit is characterized by a short time constant.

II. BASIC STRUCTURE OF SOLID STATE TRANSFORMER

Smart transformer caters to a wide variety of applications, ranging from alternative power generation to traction locomotives, power grid and electric industries, and others. Smart transformer is used in a wide range of applications, which would facilitate the smooth transition from AC to DC and DC to AC, besides voltage conversion. Alternative power generation is the most dominant application off Smart transformer driving the market growth. Increasing adoption of renewable power sources, such as wind & solar energy, traction locomotives, are major factors boosting the adoption of Smart transformer globally. The world smart transformer market is driven by, increasing preferences for renewable energy source, growing use of traction locomotives & electric vehicles and heavy investments in smart grids & energy systems. In addition, new renewable energy sources such as tidal energy for power generations have boosted research and development activities in the field of electric distribution network, further, driving the market growth.

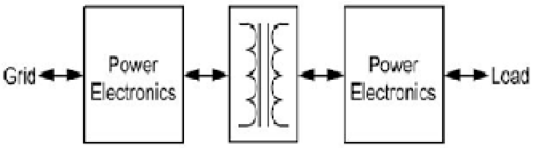

Figure 1: Basic structure of solid state transformer

III. WHY SOLID STATE TRANSFORMER

The step down transformers are one of the pivotal power system apparatus at the distribution level. More than 35% of the total cost of distribution network is for distribution transformers. Moreover, the regular failures and maintenance cost of these transformers is an additional burden for the utility. Though robust in design, the conventional distribution transformers have following limitations:

- Sensitive to harmonics
- Voltage drop under load
- No control mechanism from system disruptions and overloads
- Environmental concerns regarding mineral oil
- Poor performance under dc-offset load unbalances
- No Power factor improvement

IV. FUNCTIONAL DIAGRAM OF SMART TRANSFORMER

The incoming voltage is converted into a high frequency AC through the use of power-electronics based converters before applied to the primary side of the HF transformer. The opposite process is performed on the HF transformer secondary side to obtain an AC and/or DC voltage for the load. The power transfer at higher frequency helps in reduction in weight, as well as size, of a transformer.

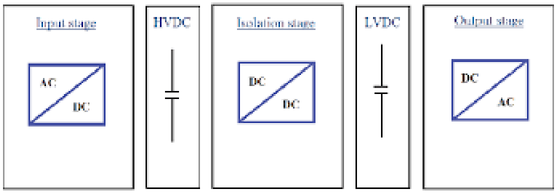

Figure 2: Functional Diagram of solid state transformer

Generally, the smart transformer as shown in figure 2 includes following three stages:

- The rectification stage first converts a high-voltage ac to dc at high voltage dc bus.
- In second stage, high-frequency transformation is used to convert higher dc voltage to lower level; generally this is called as dc/dc converter stage. At the output of this stage (at low voltage dc bus) a regulated low dc voltage at desired level is available
- The last inversion stage helps to produce a desired, regulated low ac voltage (ac bus).

Therefore, the ST is called as a three-port energy router and power exchanger. It can integrate the distribution system, residential ac system, and envisioned dc system. In order to improve the system efficiency, the dc type sources and dc load are connected to dc port, whereas the ac type sources and ac load are connected to ac port. The three-port characteristics of SST make it very suitable to enable a new microgrid that exhibits better performance compared with conventional ac and dc micro grids.

V. ADVANCEMENT IN MATERIAL OF SMART TRANSFORMER

In these power electronic converters, power switches are used such as MOSFET, IGBT etc. In order to design SST, mainly high frequency transformer design plays important role. In case of design, it examines mainly efficiency of high frequency transformer depending on the operating condition, wire and core selection and electromagnetic analysis to have a required magnetizing and leakage inductance for converter. Even though the high operating frequency makes the transformer compact, there are many restraints which have to be considered, such as insulation, power loss and cost as well. The transformer losses are strongly related to frequency. These losses contribute to the economics of the system in which they operate. There are two losses mainly, contributing to the total transformer losses are:

1. The core loss (which represents the no load loss)
2. The winding or copper loss (which represent the load loss). The core loss i.e. the power dissipated in the core consists of Eddy current and hysteresis losses.

- Hysteresis loss – It is consumed in the continuous reversal of the magnetic field due to the changing direction of the magnetizing current. This loss is easier to control through the design stage than the eddy current loss.
- Eddy current loss – It is caused by circulating currents in the body of the core. This current is produced due to the induced voltage when the magnetic flux is changing.
- High frequency transformer is designed as dry-type for environmental and safety issues. Depending on the frequency.

VI. COMPARISON OF ST & CT

The Conventional Transformer (CT) has been used since the introduction of AC systems for voltage conversion and isolation. The widespread use of this device has resulted in a cheap, efficient, reliable and mature technology and any increase in performance are marginal and come at great cost. Despite its global use, the CT suffers from several disadvantages. Some of these are:

- Bulky size and heavy weight
- Transformer oil can be harmful when exposed to the environment
- Core saturation produces harmonics, which results in large inrush currents
- Unwanted characteristics on the input side, such as voltage dips, are represented in output waveform Harmonics in the output current has an influence on the input. Depending on the transformer connection, the harmonics can propagate to the network or lead to an increase of primary winding losses.
- Relative high losses at their average operation load. Transformers are usually designed with their maximum efficiency at near to full load, while transformers in a distribution environment have an average operation load of 30%.
- All CTs suffer from non-perfect voltage regulation. The voltage regulation capability of a transformer is inversely proportional to its rating. At distribution level, the transformers are generally small and voltage regulation is not very good.

The Solid State Transformer (SST) provides an alternative to the CT. It should be noted that the SST is not a 1:1 replacement of the CT, but rather a multi-functional device, where one of its functions is transforming one AC level to another. Other functions and benefits of the ST which are absent in the CT are: High controllability due to the use of power electronics.

- Reduced size and weight because of its high-frequency transformer. The transformer size is inverse proportional to its frequency; hence, a higher frequency results in a smaller transformer.
- Unity power factor because the AC/DC stage acts as a power correction device. Unity power factor will usually increase the available active power by 20%.
- Not being affected by voltage swell or sag as there is a DC link in the solid-state transformer.
- Capability to maintain output power for a few cycles due to the energy stored in the DC link capacitor.
- Function as circuit breaker. Once the power electronics used in the solid-state transformer are turned off, the flow of electricity will stop and the circuit is interrupted.
- Fast fault detection and protection.

VII. SPECIFICATIONS OF SMART TRANSFORMER

With incorporation of the solid-state technology into the distribution transformer, many new specifications can be realized as:

1) Voltage sag compensation: When the input source voltages compensate for the deficit and maintain constant output voltage. The total period of compensation, as a function of the amount of energy storage, can be adapted to the specific need of the customer.
2) Outage compensation: Similar to voltage sag compensation, the ST can provide full voltage compensation or the period needed by the built-in energy storage.
3) Instantaneous voltage regulation: If the input source voltage fluctuates due to power system transient or other load effects, the ST will maintain constant output voltage, because it has the energy buffer.

4) Fault isolation: The ST can act as a circuit breaker to isolate the power grid from load fault and vice versa.
5) Power factor correction (and reactive power compensation): The ST can maintain a unity power factor within its power rating. The ST can also generate or absorb reactive power as required by the system.
6) Harmonic isolation: Non-linear loads produce harmonic-distorted current that tends to propagate back to the primary side of the transformer. The ST will maintain a clean input current with a unity power factor.
7) DC output: In addition to the 120/240V AC voltage, the ST has 400V DC output, which allows easier connection to distributed energies.
8) Metering or advanced distribution automation: The ST has advanced monitoring capabilities including instantaneous voltage, current, power factor, harmonic percentage, kWh and fault current or voltage information as well.
9) Environmental benefit: Unlike the conventional liquid immersed transformer, the solid-state transformer is an oil-free transformer and friendly to environment.

VIII. APPLICATIONS OF SMART TRANSFORMER

A ST can be used instead of the conventional transformer (CT) in any electrical system, but because of its additional advantages and functions, the application of the ST in certain areas is much more attractive. Examples of these applications are:

1) Locomotives and other traction systems: The transformer used in current locomotive vehicles is 16.7Hz and is ±15% of the total weight of the locomotive. The ST can provide a significant weight reduction. Additionally, the ST is also able to improve the efficiency, reduce EMC, harmonics and acoustic emissions.
2) Desired energy generation: Offshore generation, whether from wind, tidal or any other source, can benefit from the reduction in weight and size. This reduction leads to smaller and thus, cheaper offshore platforms. Another advantage is that the ST can achieve unity power factor, thus, increasing the efficiency in power transmission.
3) Smart Grids: In future power systems, the usage of renewable generation is expected to increase, and will require an energy management scheme that is fundamentally different from the classic methods. For fast and efficient management of the changes in different loads and sources, the ST can be used to dynamically adjust the energy distribution in the grid. The ST will manage the flow of energy. For this reason, the ST is sometimes also called an energy router.
4) DC Source for Power Delivery: The ST 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 (ST) to generate the DC is a means of controlling the system and interrupting fault currents.
5) Integration with other systems: The LV DC link in the ST 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.
6) Application between generation source and load or distribution grid: In this scenario, the ST can enable constant voltage and frequency at its output if the input voltage and frequency are variable. The ST can also allow the energy transport between source and load or grid to occur at unity power factor. This results in better utilization of the transmission lines and increased flow of active power. Another function, which the ST can provide is to improve system damping during the transient state.
7) Application between two distribution grids; One of the features of the ST is that it does not require both grids to have the same voltage level, frequency or to operate synchronously. The ST can be used to control the active power flow between both grids. It can also be used as a reactive power compensator for both grids. Special application is made, when considering the commercial side of power systems.
8) Connection between the MV and LV grid: In contrast to the CT, the ST can accurately control the amount of active power flowing from the MV to the LV grid. This is useful if the LV side also has generation sources such as PV panels. The ST can limit the amount of energy that flows back and forward through certain parts of the grid, to avoid overload of transmission lines with limited current carrying capacity.
9) Connection between MV-grid and loads: LV loads are often unbalanced which can lead to harmonics disturbances in the voltage and asymmetrical voltages. A neutral wire is added in order to eliminate these disturbances and achieve a more symmetrical voltage. When the imbalance is large or consists of many non-linear loads, the addition of a neutral wire might not nullify the disturbances completely. In this case, the ST can help by generating a voltage that hardly suffers from unbalanced and non-linear loads.
10) Application as interface for distributed generation and smart grids: Distributed energy sources, such as photovoltaic arrays and wind turbines, provide a variety of electric sources. These sources often have a

varying voltage or frequency or can even be a DC voltage. The ST is flexible enough to allow connection of these sources to the traditional grid.

IX. CONCLUSION

This paper highlights the basic structure of and working of solid state Transformer. This paper also states the comparison between conventional transformers and solid state transformers. However, a development which would not account for the component challenges, such as efficiency, reliability and cost, could be completely unsuccessful. The main challenge of the actual research field is to develop the possible future services sketched in Fig. 1 and discussed in Section IV , In these sense, the following fields are individuated as promising research areas:

1. Identify which smart grid services could better benefit from the high dynamic behavior of the ST and by its capability to widely vary its voltage and current waveforms.
2. Identify which grid conditions challenge most the Smart Transformer components and how communication, sensing and control can provide virtually the same robustness that traditional transformer had.
3. Define for each stage of the Smart Transformer, the optimal power level, the adopted topology and sizing it in relation to the offered services (point 1) and disturbances to which it is subjected (point 2).
4. Define for each stage of the Smart Transformer the suitable control which could at first guarantee safe operation (point 2), still offering the services for which the ST will be implemented (point 1).
5. Focus on all the enabling technologies starting from modules and passive components but not neglecting electronics, sensors and protections and identify the breakthrough enabling technologies.

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