A REVIEW ON ACTIVE POWER ELECTRONIC TRANSFORMER

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Abstract - In every country, transformer is the main source for transmission and distribution. Transformer is a device which can transfer electrical energy from one place to another with constant frequency. Nowadays distribution transformers are considered among the huge and expensive equipment because of their massive iron core and heavy copper windings. The main solution for voltage change in transformer is only possible by varying the number of turns. Active power electronic transformer is a programmable device that can vary the frequency and voltage as we desire and uses power electronic converters for the same. It has offered enabling technologies for the power quality enhancement, considerable reduction in size. In addition to voltage transformation and good isolation which they bring about, these transformers are also associated with significant advantages, including considerable reduction in the size, power quality improvement, etc. Active power electronic transformers, composing an important part of the smart grid, could have many roles in that variable system. Active power electronic transformer is used later as a standard building block in more complex systems to guarantee the power quality on the HV grid side.

Keywords- Power Electronic Transformer, three stage topology, Solid state Transformer, voltage source converter

I. INTRODUCTION

A transformer is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. Transformers are used to increase or decrease the alternating voltages in electric power applications. A varying current in the transformer's primary winding creates a varying magnetic flux in the transformer core and a varying field impinging on the transformer's secondary winding. This varying magnetic field at the secondary winding induces a varying electromotive force (EMF) or voltage in the secondary winding due to electromagnetic induction. Making use of Faraday's Law in conjunction with high magnetic permeability core properties, transformers can be designed to efficiently change AC voltages from one voltage level to another within power networks.

Fig 1: Transformer
II. TRANSFORMER

An ideal transformer is a linear transformer that is lossless and perfectly coupled. There are no energy losses and flux is completely confined within the magnetic core. Perfect coupling implies infinitely high core magnetic permeability and winding inductances and zero net magneto motive force. A varying current in the primary winding of the transformer creates a varying magnetic flux in the core and a varying magnetic field is produced on the secondary winding. This induces a varying Electro Motive Force (EMF) or voltage in the secondary winding. The primary and secondary windings are wrapped around a core of infinitely high magnetic permeability so that all of the magnetic flux passes through both the primary and secondary windings. With a voltage source connected to the primary winding and a load connected to the secondary winding, the transformer currents flow in the indicated directions. According to Faraday's Law, the same magnetic flux passes through both the primary and secondary windings in an ideal transformer; same voltage is induced in each winding. The primary EMF is sometimes termed counter EMF. This is in accordance with Lenz's law, which states that induction of EMF always opposes development of any such change in magnetic field.

III. EFFECT OF FREQUENCY

The EMF of a transformer at a given flux density increases with frequency. By operating at higher frequencies, transformers can be physically more compact. When frequency increases core loss and conductor skin effect also increases. At a higher frequency transformer operation lead to reduced magnetizing current and at lower frequency, the magnetizing current will increase. Operation of a transformer at other than its design frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. At much higher frequencies the transformer core size required drops dramatically: a physically small and cheap transformer can handle power levels that would require a massive iron core at mains frequency. The development of switching power semiconductor devices and complex integrated circuits made switch-mode power supplies viable, to generate a high frequency from a much lower one change the voltage level with a small transformer, and, if necessary, rectify the changed voltage.

IV. DISTRIBUTION ELECTRONIC POWER TRANSFORMER

Many active power filters are introduced to improve power quality in case of nonlinear loads and the structure of the distribution system is becoming more complicated. Recently, a new type power transformer, which is based on power electronics and high frequency link, has been studied extensively. Here, the power electronics based distribution transformer with the high frequency link, termed as Distribution Electronic Power Transformer (DEPT), has been explored.

There are two approaches to realize the DEPT. The one is without dc link and the other is with dc link. The voltage or current in either side of DEPT can be flexibly controlled through Pulse Width Modulation (PWM) technology. Fig 2.6 shows a basic diagram of the DEPT with a primary and secondary static converter and high frequency transformer. The power-frequency (50 or 60 Hz) input sine wave voltage is first converted into a high frequency signal by the primary side converter, and then, magnetically coupled to the secondary. In the secondary side, the high frequency signal is unfolded into a power-frequency waveform. Here, the primary function of the high frequency transformer is to achieve isolation between the primary and secondary system.

V. SOLID STATE TRANSFORMER

A smart transformer is a solid-state device that serves as a power load with the ability to distribute and provide optimal power to loads. This “intelligent device” is a composed of electrical hardware like high-powered semiconductor components, conventional high-frequency transformers and control circuitry whose purpose is to arrange a high level of supple control to power distribution networks. If some communication capability is added to this arrangement then the resulting setup
would be known as a smart solid state transformer. The solid state transformer 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 shown in Fig 2.7. The basic operation of the SST is firstly to change the 50/60 Hz AC voltage to a high frequency one, then this high frequency voltage is stepped up/down by a high frequency transformer with dramatically decreased volume and weight, and finally shaped back into the desired 50/60 Hz one to feed the load. In this sense, the first advantage that SST may offer is the reduced volume and weight compared with traditional transformers.

![Solid State Transformer configuration](image)

Fig 2: Solid State Transformer configuration

The high frequency transformer is the main component in the SST, which replaces the traditional 50/60 Hz transformer. The transformer losses are strongly related to frequency. These losses contribute to the economics of the system in which they operate. High frequency transformers in solid state transformer point out for the performance and overall efficiency of SST system, so it is important to select the right materials and optimize the design to fulfill all requirements in the operating condition. At low frequency, the eddy currents can be reduced by laminating the core in the direction of the induced voltage. High frequency transformer is designed as dry-type for environmental and safety issues.

- They are energy efficient. This means that they can deliver much more power through similar wires at a faster rate. It is estimated that their power transmission capability is 10 times greater than the traditional transformers.
- These transformers have the ability to deliver diverse power like 400 Hz services, 3 phase power and DC service through a single phase line. Not only this, but the power quality is also much refined.
- Another major advantage is that it is cost-effective. Since the transformer can be used in different configurations, so there ought to be less parts and inventory. With lesser number of parts, both the costs of manufacturing and maintenance are reduced.
- Last but not the least, this device is environmental friendly. There are no perilous liquid dielectrics or hazardous elements in it.

VI. ACTIVE POWER ELECTRONIC TRANSFORMER

The APET is a new type of transformer that realizes voltage transformation, galvanic isolation and power quality enhancements in a single device. The APET is suitable for the use in the power systems that comprise renewable energy sources, energy storage devices as well as different type of loads. Thus the bi-directional power flow is the most important requirement that the APET has to fulfill. The topology consists of the controllable input (AC/DC), the isolation (DC/DC) and output (DC/AC) power electronic stages to shape the input current, to correct the input power factor, and to regulate the voltage of primary DC bus. Second stage is an isolation stage which provides the galvanic isolation between the primary and secondary side. In the isolation stage, the DC voltage is converted to a high (MF) transformer and is rectified to form the DC link voltage. The output stage is a voltage source inverter which produces the desired AC waveforms.
VII. ACTIVE FUNCTIONS OF APET

A. Power Control

One of the possible active functions that could be implemented by the APET is the power flow control between the different input and output ports. Controlling the reactive power and the power factor has been reported as one of the basic objectives. This power factor correction could be implemented in high voltage (HV) or low voltage (LV) terminals.

B. Voltage Control

To control the voltage in the different ports of the APET is another function that has been widely studied in different works. The APET operates as a Dynamic Voltage Restorer (DVR) when compensating the voltage harmonics, improving the voltage quality of one or different ports, and usually needs some energy storage system.

C. Current Control

The APET can also control the current that flows into or from its ports, cancelling the current harmonics demanded by non-linear loads operating as an active power filter (APF) or even can supply pre-distorted voltage waveform for cancelling the current harmonics demanded by these loads, or compensating the current unbalance. The APET can also control the current transient after connecting or disconnecting loads, preventing current overshoots and oscillations.

D. Integration Of Distributed Generation

The APET can be used as a smart device for integrating the distributed generation (DG) mainly the one produced from renewable energies, as photovoltaic or wind generation plants.

E. Increase Interconnection Possibilities

The APET could have different types of input/outputs ports: DC ports, AC single-phase ports, AC three-phase ports and others. This allows using the APET for interconnecting electrical grid with different voltages, frequencies (50 Hz, 60 Hz, also DC) and number of phases.

F. Improving Reliability

The APET could improve reliability by integrating distribution generation.

VIII. PROPOSED SYSTEM

Numerous topologies have proposed for the Active Power Electronic Transformer, consisting of single-stage, two-stage and three-stage topologies. In recent years, different topologies have been presented for realizing the PET and the three stage APET topology i.e. topologies with both HV and LV dc-links has come out to be the most promising. The voltage or current can be separately controlled in each stage. It is possible to add distributed energy storage devices or distributed energy sources. HV and LV dc-links enhance the ride-through capability of the APET and allow power quality improvement in the input and in the output. This topology consists of an input stage (AC/DC), an isolation stage (DC/DC) and an output stage (DC/AC).

Fig3: Three stage topology of PET
A. Input Stage

It is a three or single phase PWM rectifier, which is used to convert the primary low frequency AC voltage into the DC voltage. It is also utilized to shape the input current, to correct the input power factor, and to regulate the voltage of primary DC bus.

![Fig 4: Structure of the proposed input stage](image)

B. Isolation Stage

It consists of a single phase high frequency voltage source converter (VSC), which converts the input DC voltage to AC square voltage. Here, the DC voltage is converted to a high frequency square wave voltage, which is coupled to the secondary of HF(or MF) transformer and is rectified to form the DC link voltage. It also provides the galvanic isolation between the primary and secondary side.

![Fig 5: Structure of the proposed Isolation stage](image)

C. Output Stage

It is a voltage source inverter which converts DC to AC waveforms. It consists of LC filter 1, sine wave modulator, H-bridge inverter and LC filter 2.

![Fig 6: Circuit of output stage](image)
IX. FEATURES AND APPLICATION OF APET

A. Advantages

- Provides active and reactive powers compensation.
- Flexible regulation of the voltage and power.
- Remove the power quality disturbances such as sag, under voltage, over voltage and voltage flicker.
- It is compact, has low weight and compact volume.
- Eliminates the necessity for toxic dielectric coolants: Mineral oil, beta oil, silicone are widely used coolant materials, cost of coolant higher and its replacement also difficult.
- APET allows bidirectional flow of active power between the utility and the micro-grid.

B. Disadvantages

- To introduce power device, gate drive, heat sink and control circuit in the proposed model, lower weight cannot be guaranteed until careful designing are preferred.
- To get high efficiency and reliability high frequency and voltage power device are needed. But SCR, IGBT, etc are low frequency device, so they have to connect in series for PET.
- High volt and high frequency transformer is a main component. To get high voltage, power, frequency many additional requirements are needed. They are
  - Appropriate selection of magnetic material
  - Advanced thermal design, i.e. space utilised should be minimum
  - Oil free operation

C. Applications

- APET can provide desired waveform in each phase independently, and hence it is used in Universal Power Quality Conditioner (UPQC).
- APET can transfer active and reactive power from one port or phase to another port or one phase. This in power distribution system is very useful for Interline Power Flow Controller (IPFC).
- APET can provide symmetrical three phase voltage from an asymmetrical ac source in the form of an Uninterruptible Power Supply application (UPS).
- APET can play a role in providing useful power from variable low voltage dc source that is suitable for renewable energy applications such as photovoltaic and fuel cell.
- APET will have a major impact on the utility industry and the places such as aircraft and shipboard where the high quality power conversion is very desirable.

X. CONCLUSION

An active power electronic transformer (APET) could have many roles in a smart grid. In addition it provides galvanic isolation between the input and the output, thus, the input voltage disturbances have no effect on the output ones, and vice versa. In general, the power quality is improved in both input and output ports. The increasing number of applications of power electronic interfaces in smart grid will increase the EMI level of the environment. The APET can compensate both the active and reactive powers. Smart grids related systems including APET have to meet requirements regarding power quality.

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