

TAP CHANGER FOR DISTRIBUTED POWER

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ABSTRACT

United Utilities has identified that the introduction of a combined heat and power plant into a new estate in their LV distribution network will give rise to the possibility of reversal of power flow through the Distribution Transformer at periods of low loading with consequent rise in line voltage. Since such a voltage rise might violate the statutory limits a cost effective method of limiting this voltage is essential. The solution identified is to switch between two predefined taps on the distribution transformer at preset times of the day based on historical loading data.

The tap changer being developed uses a set of vacuum switches operated from a single armature to give a simple and hence reliable scheme. The power circuit is designed to integrate within the transformer tank. The control is from a single electronics board that mounts on the substation wall for convenient adjustment and monitoring of the tap changer settings. The primary operation is time based although a means of switching the tap according to the voltage level of the LV network has been included. In both cases care has been taken to prevent the possibility of the tap change operation “hunting”. The development is well advanced and should be ready to go into service trials in mid 2007.

INTRODUCTION

Combined Heat and Power (CHP) is a recognised method of significantly improving the efficiency of power generation. With increasing government incentives its use is growing throughout the UK. United Utilities (UU) has been studying the problems associated with the introduction of CHP systems within the Manchester Area, [1]. They have identified that during periods when the local load requirement is reduced, for example in the early morning, the generated power may reverse the power flow through the Distribution Transformer. The level of AC regulation present in the power system means that such a reversal will cause a significant rise in the LV network voltage to a level beyond the limits defined by security standards. A simple solution to alleviate this is to set the distribution transformer to a lower voltage tap than normal.

Conventional On-Load Tap Changers (OLTCs) are fitted to distribution transformers but have a cost considerably in excess of the transformer, have size comparable to the transformer and have a reputation for “hunting”, i.e. repeatedly tapping up and down. Furthermore the control is not designed to manage reverse power. For this application the requirement is to switch only between two preset tap

settings, equivalent to the diverter function in a conventional OLTC.

Based on research into advanced techniques for OLTCs for transmission transformers, Areva T&D proposed a design based on a patented design approach using vacuum switches, [2]. A development project was agreed with UU to be funded by the UK regulator (Ofgem) Innovation Funding Incentive (IFI) initiative under which the development costs can be recovered on a limited basis.

VACUUM-SWITCH-BASED TAP CHANGING

Vacuum switches are commonly used for medium voltage power breakers and are known to be high reliability components. They are also commonly used in synthetic laboratory testing of power equipment because of their ability to switch relatively high levels of voltage and current to a timing precision of better than 1ms. The proposed tap-changing scheme takes advantage of the unique properties that vacuum switches possess, specifically:

1. The armature movement is small for large voltage withstand, typically 10kV/mm, enabling rapid operation.
2. The arc voltage is very small and stable, being typically 20V to 60V.
3. The arc recovery is very rapid, being typically better than 0.5 μ s.

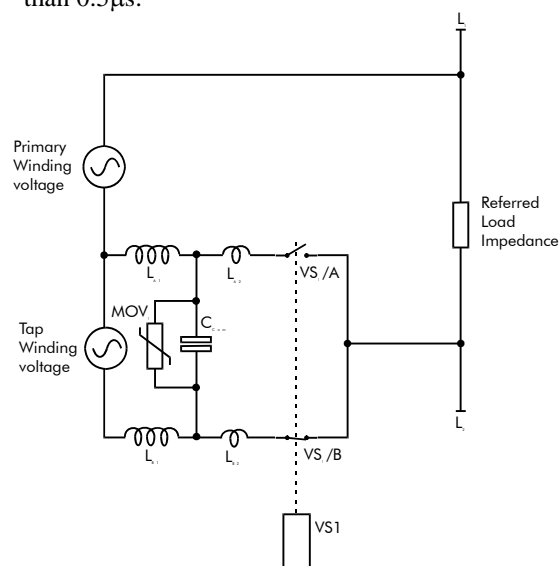


Figure 1: Basic On-Load Tap Changer Circuit

Figure 1 presents the circuit on which the tap changer is based. The values of the inductors and capacitor are related to a commutation resonance associated with the fast recovery time of the vacuum switch and so have negligible

voltage drop at 50Hz. This also means that the capacitor voltage follows the tap voltage closely. The circuit operation assumes that at a chosen instant there is a finite tap voltage so the capacitor has charge. It is also assumed that the load current will cause arcing as the conducting vacuum switch is opened, maintaining the flow of current to the load.

To cause the tap change a drive amplifier is switched into a drive coil in the actuator that operates the vacuum switches. A finite time is required for the current to build in the drive coil to a sufficient level to overcome the actuator latching force, typically 7ms. Additional time of about 3ms is then required as the contacts open until a gap develops of about 2mm that is sufficient to hold off the tap voltage. The second vacuum switch then closes and the capacitor is discharged through both vacuum switches, causing a resonant commutation process. As the resonant circulating current swings it cancels the load current in the first vacuum switch and the arcing ceases.

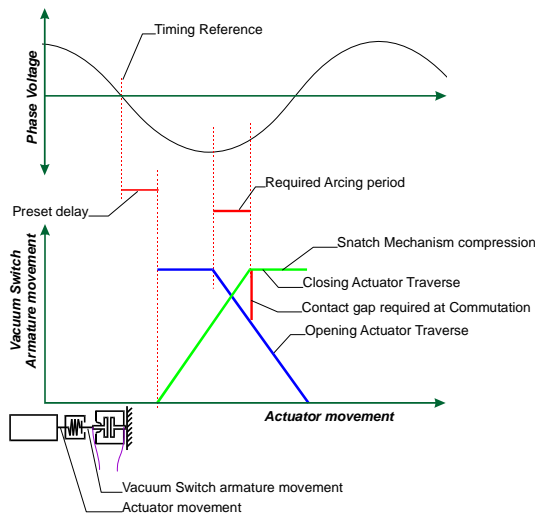


Figure 2: Tap Changer Operation

The timing of the commutation is critical since it must be ensured that the commutation capacitors for all three phases will have sufficient charge. This is assisted slightly by the arcing voltage that offsets the ideal commutation point so that one phase passes through zero current causing natural commutation. Therefore only two commutation circuits are required in practice. Figure 2 illustrates the tap change process and highlights that, by adding a third preset delay and by referencing the start of the process against the zero crossing of the tap voltage, the tap change process can be set to a specific point on wave.

Distribution transformers include an “Off-Load” tap changer as standard, giving a range of $\pm 5\%$ in steps of 2.5%. To make the tap changer compatible with the most common tap arrangement requires the basic tap changer design to be extended to the form illustrated in Figure 3.

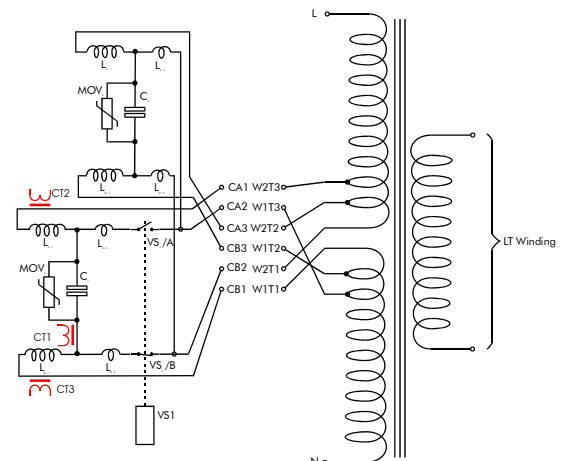


Figure 3: Full Tap Changer Power Circuit Arrangement

The tap changer must operate between any two of the taps and the site engineer can set that this in-situ.

RELIABILITY & CONTROL

A study into the reliability of the tap changer design highlighted that very high reliability could be achieved provided the power circuit and the control circuit are addressed separately. The estimate of reliability for an equivalent transmission transformer scheme is of 30 years guaranteed life, based on a total of 500,000 operations (BS EN 60214: 1998). The vacuum switches and actuator have a fatigue life pedigree of millions of cycles and the power inductors also have a very high reliability. The main failure modes are due to failure in the commutation capacitor and in the insulation of the current transformers (CTs). The capacitors are of a segmented type used for snubbing power electronics and so internal failures are isolated. Thus they will not fail short circuit but a gradual reduction in their capacitance will be observed over time to a point where they may need to be replaced. All the CTs for a single phase have been encapsulated into a single box with insulating tubes running through to carry the primary conductors. A full fault current safety earth is also fitted over the tube in case the insulation is compromised. Thus the power circuit to be contained within the transformer tank has been designed to have a high reliability.

In contrast to the power circuit, the failure rate of electronics used for control is inherently poor. To maintain operation in the event of a control fault occurring two-way redundancy and three-way voting has been included. The latching property of the actuator means that with careful design the electronics board can be removed without the need to de-energise the transformer, i.e. it can be “hot swapped”. Thus a detected fault will raise an alarm and the second drive channel will be used until the board is replaced. It should thus be sufficient to check the tap changer operation on a routine basis to ensure 30-year life of the tap changer without interruption.

Figure 4 illustrates the realisation of the timing process illustrated in Figure 2. A primary timing reference is taken from integrating the output from a CT monitoring the commutation capacitor current (CT1). The commutation process is limited in terms of the load current that can be cancelled and the minimum tap voltage that must be present, the output from both the timing reference CT, CT1, and additional CTs monitoring load current, CT2 and CT3, must be checked for magnitude to ensure both load current and tap voltage are within the required limits.

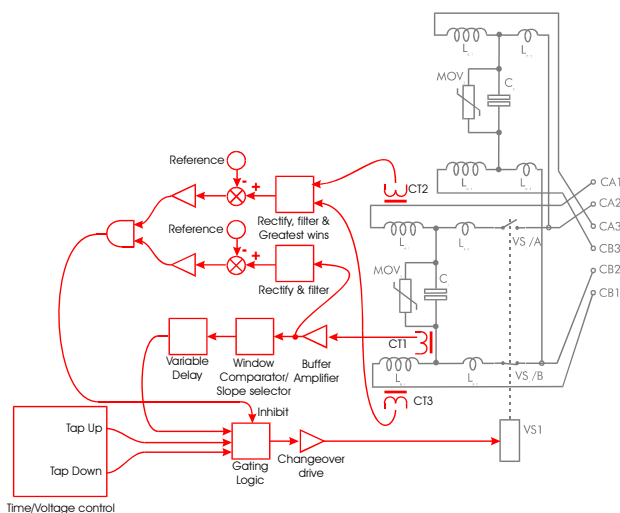


Figure 4: The control functionality

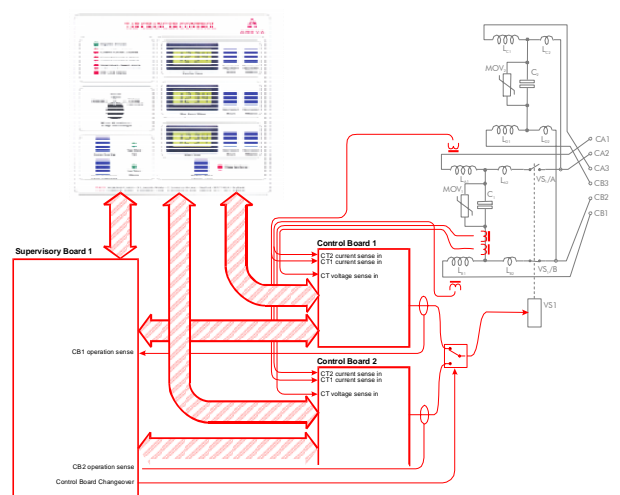


Figure 5: Full Redundant Control

The full redundant control is illustrated in Figure 5 in which the four functional blocks are shown, the display panel, the supervisory block and control blocks 1 and 2. The supervisory block and the control blocks contain the logic shown in Figure 4 with either of the two control blocks being able to drive the actuator as selected by the voting logic within supervisory block. The supervisory block manages the control panel interface and relays the time information to the control blocks so that each block contains an independent record of the timing information. Voltage regulation has been included to the control that will

cause a tap change if the RMS secondary voltage rises above or falls below its terminal requirements. A calculation based on ideal supply settings for a range of load power factors shows that the two switch thresholds are sufficiently separated to prevent “hunting” from taking place.



Figure 6: Electronics control board

The electronics is mounted onto two boards, one for the display and the other containing all the control electronics, Figure 6. Analogue electronics is used for buffering and processing the CT signals, while the remaining functionality is contained within three Field Programmable Gate Arrays (FPGA), one for each of blocks shown in Figure 5. The drive for the vacuum switch actuator coil is from a two-quadrant H bridge, the supply being from a pre-charged 50V, 100mF capacitance, divided into an array of capacitors that are also mounted on the board. The auxiliary supply for the logic is taken from a charged super-capacitor to protect against loss of mains supply and give the electronics a hold up of up to half an hour. This can be extended if required by increasing the number of super-capacitors.

The card carrying the display electronics provides a mounting for the display and controls and mounts straight to the front panel. The selection of the electronics to be incorporated onto this card has been chosen to permit future upgrading. This will permit custom boards to be developed so that the equipment can be easily integrated into remote automation schemes specific to the client to allow remote control and monitoring. This has other potential benefits in that since the equipment contains means of monitoring the line current, the equipment offers an inherent remote “Fault Passage Indicator”.

NON INVASIVE MECHANICAL DESIGN

Several arrangements of the mechanical design for the OLTC have been considered, including a version in which it was fitted in a separate housing from the transformer. Standard sub-stations within the UK do not have sufficient clearance around the transformer inside the enclosure to position a separate, free-standing tap changer but do have adequate clearance above the tank cover making this the best practical arrangement. Thus the present OLTC has been situated on top of the transformer and is fixed in position using a bolted flange that would normally attach

the transformer cover to the main tank, Figure 7. The tap changer is not submerged in insulating oil therefore normal oil levels above transformer windings are maintained and standard oil level gauges can be used. This arrangement also enables the tap changer to be retrofitted to any existing distribution transformer with no modification to the tank.

The mechanism is made up of vacuum switches configured on a single shaft arrangement to give simultaneous 3-phase operation. A magnetic actuator has been adapted to deliver the required speed and precision to achieve the correct switch commutation to operate the mechanism. AREVA T&D VS3-C vacuum switches have been selected as having the characteristics required for this application:

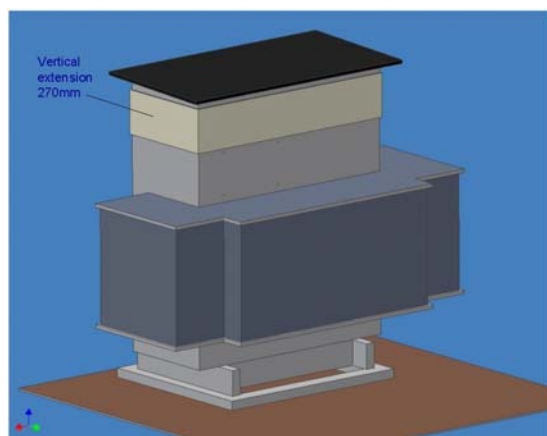


Figure 7: Tap Changer fitted to a 1MVA Distribution Transformer.

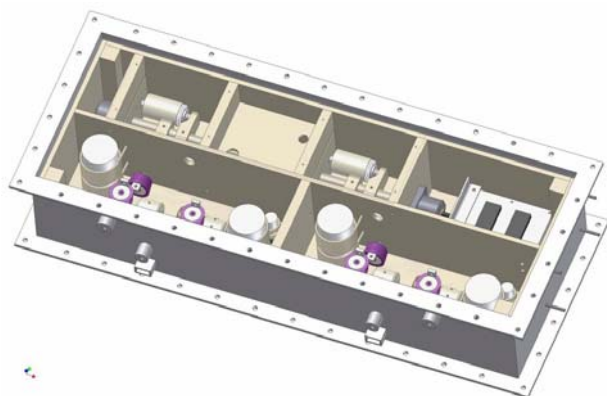


Figure 8: The Tap Changer Layout

A major consideration for the system is the method of insulation. Mounting the system outside the oil means that to achieve the creepage between phases the three pairs of vacuum switches and the two commutation circuits must be compartmentalised and sealed, Figure 8.

The control is housed in a separate box, Figure 9, which is sealed against vandalism so the display panel is only visible when it has been unlocked and the front cover opened. The box is wall mounted with armoured cable coupling it to the power system. The control panel is arranged to be simple to operate and set.



Figure 9: Control box layout

CONCLUSIONS

A simple changeover type on-load tap changer has been presented that has been custom designed to address a potential problem created by the introduction of distributed CHP. The rise of domestic power generation means that there is likely to be an increasing need for such equipment in future. The principle of operation is based on a novel, patented scheme that utilises the unique properties of vacuum switches to give a product that will integrate easily with the transformer and that can link into remote substation operating systems. The design is flexible and can be adapted fit a wide range of existing transformer designs. The simple form of the tap changer means that the projected cost of the equipment should be much less than an equivalent conventional tap changer. Maintenance should only be required to service the electronic control; the power circuit has a projected life in excess of 30 years. A prototype tap changer is at present under construction and should be ready for testing early in 2007. It is presently planned to start field trials mid 2007.

REFERENCES

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- [2] C.Oates, 2006, "An On-Load Tap Changer", Worldwide patent WO2006103268 (A2)