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Original scientific paper

ANALYSIS OF AFFECTED PHENOMENA ON ELECTRONIC OLTC DESIGN FOR DISTRIBUTION TRANSFORMERS*

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A b s t r a c t: Voltage regulation is nowaday usually reserved for regulating the voltage on HV and MV network. By including more and more of distribution generation automatic voltage regulation on distribution transformers becomes an undeniable need. At the moment mostly used type of tap-changer is electromechanical. However in a recent time there are a lot of researches about electronic OLTC (on-load-tap-changer) due to their advantages over electromechanical switches. Since electromechanical switches are robust, respond slower, and operate from tap-to-tap, there is surely a need and a reason for investigation and consequently application of the electronic OLTC in a distribution network in a close future.

Key words: solid-state OLTC; voltage regulation; smart-grid; distribution generation

АНАЛИЗА НА ПОЈАВИТЕ ШТО ВЛИЈААТ ВРЗ ДИЗАЈНОТ НА ЕЛЕКТРОНСКАТА ПРЕКЛОПКА (OLTC) ЗА ДИСТРИБУТИВНИ ТРАНСФОРМАТОРИ

А п с т р а к т: Во најголем број дистрибутивни мрежи се користи рачна регулација на напонот со помош на среднонапонско-нисконапонските трансформатори. Меѓутоа, со позначителното интегрирање на дистрибуираните извори на електрична енергија, неопходна е автоматска регулција на напонот. Досега најкористени се електромеханичките регулаторни преклоки. Во меѓувреме се прават многу истражувања за употреба на електронските регулаторни преклопки OLTC, кои имаат значителни предности во однос на електромеханичките. Предностите на целиот склоп се: помали димензии, пократко време на комутација, подобри карактеристики на заштита и на пренасочување. Денес наоѓаат сè поголема примена во автоматската напонска регулација на дистрибутивните трансформатори. Затоа е важно да се прават анализи со кои би се потврдиле предностите на овие регулатори, сè со цел нивна поголема имплементација во иднина.

Клучни зборови: електронски регулатори OLTC; регулација на напон; дистрибутивно производство

INTRODUCTION

Since it is a tendency to have a bidirectional flow of the electrical energy in a power system, there is a big challenge in a voltage regulation in distribution network [1]. Distribution transformers with electromechanical OLTCs are already widely spread since there is a need for automatic voltage regulation especially in the active MV and LV networks. There are a few models of OLTCs that are used for tap-change operations. Electromechanical tap-changers include resistor or preventative autotransformer as a diverter switch [2]. Disadvantages of a resistive and reactor tap-changer are undeniable. Slow operation time, problem with size, maintaining costs are the biggest drawbacks of this type of OLTC. Application of power electronics for automatic voltage regulation can speed up transition time from tap-to-tap, eliminate problems with lack of space and avoid additional maintaining costs.

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There are two tap-changer types based on electronics which can be a replacement of electromechanical OLTC [3].

Electronic assisted OLTC still uses mechanical switches for the tap change but with a reduction of an arc and transition time. Solid state OLTC without any mechanical counterparts shows significantly advantages in ability to jump from currently active tap to any other in only half-interval of the fundamental frequency as well as reducing noise and losses.

This paper orientates mainly on the design determination of electronic OLTC counterparts. Electronic switches and protection elements have to hold up voltages and currents in a normal operation state. By using transformer winding parameters currents and voltages on each electronic switch in a normal operation state can be defined. This is the base for electronic switch determination and protection system settings [4].

In the advanced networks voltage regulation is a big challenge for distribution network operator [5]. By adding distribution generation with its unpredictable generation, effective and fast voltage regulation becomes a demand. Low voltage mostly industrial networks can change voltage conditions on household terminals in a very short period of time [6]. When this typical load as well as distribution generation are involved in a network it is mandatory to seize a voltage between its permissible levels [7].

While electromechanical OLTCs perform to-adjacent-tap change in 2–10 s [8], solid-state OLTCs can do a tap-change in a half period of the fundamental frequency [9].

SOLID-STATE OLTC DESIGN

Steady state stresses on solid-state switches

For designing solid state OLTC and electronic switches respectively the most important is to design it for a steady state voltage across the each switch during the normal operation. Considering that taps on a regulation side are magnetically coupled with each other, commutation of the switches will effect in a changed voltage across the each switch [10]. Steady state voltage across the opened switch S_p, when S_q is turned-on can be calculated by equation (1) if the following conditions are fulfilled:

a) main windings have the same turns ratio,

b) tap windings have the same turns ratio,

c) voltage dip across taps is neglected.

$$V_{S_p} = \frac{\sqrt{2}V_{ps}|q-p|N_t}{(MN_m + KN_t)-(q-1)N_t}, \quad (1)$$

where is:

K – the number of tap windings,

M – number of main windings,

p – the index of the opened switch,

q – the index of the turned-on switch,

V_{ps} – nominal primary voltage,

N_m – turns ratio of the main winding,

N_t – a turns ratio of the tap winding to the secondary side turns ratio.

Furthermore for the peak current through the switch during the normal operation is following equation relevant:

$$I_{S_q} = \sqrt{2}\frac{S}{\nu_{\sec}}\frac{N_S}{(MN_m + KN_t)-(q-t)N_t}, \quad (2)$$

where is

S – an apparent power of the transformer,

$V_{\sec}$ – the nominal voltage on the secondary side.

N_s – the secondary winding turns ratio.

Commutation process of solid-state switches

Besides normal operation, solid state OLTC has to be designed for commutation process too. Considering that circuit is never interrupted, switches will commutate for some period of time. It is paramount to calculate a commutation current since it is one of the most important information for the protection element design that protect electronic switches from such adverse events. Positive feature of the commutation is that it reduces a spike voltage across the switch which prevents its damage in some extension. Due to slow commutation between taps in electromechanical OLTCs is necessary to include diverter switch which will reduce a commutation current. Since electronic switches commutate fast, they do not use any solution to reduce a current that happen in the commutation process.

According to the transformer's equivalent T scheme on Figure 1, variables of each winding can be converted to the other by using coefficients α_n. Coefficient α_1 converts secondary, and α_2 tertiary side variables to primary.

$$\alpha_1 = \left(\frac{MN_m + (K-1)N_t}{N_s}\right)^2 \quad (3)$$

$$\alpha_1 = \left(\frac{MN_m + (K-1)N_t}{N_t} \right)^2 \tag{4}$$

$$\left[v_{in.pri} R_{eq.pri} L_{eq.pri} \right] = \left[\sqrt{2} V_{ps} \sin(\omega t) R_{eq} L_{eq} \right] \tag{5}$$

$$\begin{bmatrix} R_{\sec.pri} & R_{load.pri} & 0 \\ L_{\sec.pri} & L_{load.pri} & L_{m.pri} \end{bmatrix} = \alpha_1 \begin{bmatrix} R_{\sec} & R_{load} & 0 \\ L_{\sec} & L_{load} & L_m \end{bmatrix} \tag{6}$$

$$[R_{tap.pri} \;\; L_{tap.pri}] = \alpha_2 [R_{tap} \;\; L_{tap}] \tag{7}$$

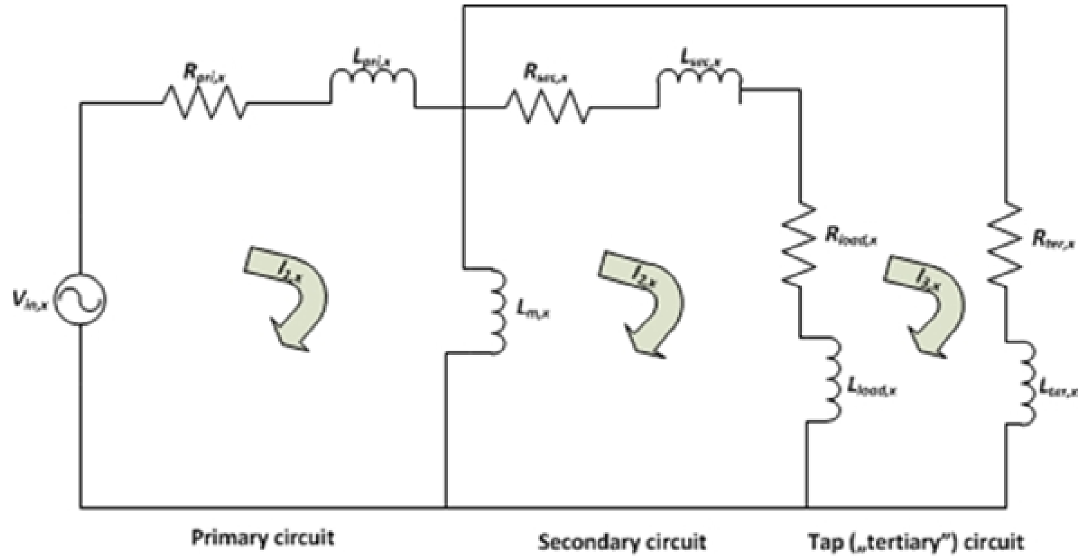

Fig. 1. *T*-equivalent scheme of transformer with solid-state OLTC

Coefficients α_3 and α_4 are used to convert variables from primary and secondary to tertiary side. They are involved in the tertiary side variables calculation.

$$a_3 = \left(\frac{N_t}{MN_m + (K-1)N_t} \right)^2 \tag{8}$$

$$\alpha_4 = \left(\frac{N_t}{N_s} \right)^2 \tag{9}$$

$$\begin{aligned} &\left[v_{in.ter} \;\; R_{eq.ter} \;\; L_{eq.ter} \right] = \\ &= \alpha_3 \left[\left(\sqrt{2} V_{ps} \sin \omega t \right) \left(\frac{\sqrt{\alpha_3}}{\alpha_3} \right) \;\; R_{eq} \;\; L_{eq} \right] \end{aligned} \tag{10}$$

$$\begin{bmatrix} R_{\sec.ter} & R_{load.ter} & 0 \\ L_{\sec.ter} & L_{load.ter} & L_{m.ter} \end{bmatrix} = \alpha_4 \begin{bmatrix} R_{\sec} & R_{load} & 0 \\ L_{\sec} & L_{load} & L_m \end{bmatrix} \tag{11}$$

$$\left[R_{tap.ter} \;\; L_{tap.ter} \right] = \left[R_{tap} \;\; L_{tap} \right] \tag{12}$$

Using Laplace transformation and putting all upper variables from t to s domain, primary and tertiary current is calculated:

$$\begin{bmatrix} I_{1,x}(s) \\ I_{2,x}(s) \\ I_{3,x}(s) \end{bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{bmatrix}^{-1} \begin{bmatrix} V_{in,x}(s) \\ 0 \\ 0 \end{bmatrix} \tag{13}$$

Afterwards, setting primary *pri* and tertiary *ter* instead of the index x in the equation (13) brings the final step in commutation current calculation where k_{ij} are substitution coefficients.

$$k_{11} = R_{eq.ref} + s\left(L_{eq.ref} + L_{m.ref}\right) \tag{14}$$

$$k_{12} = k_{21} = -sL_{m.ref}; \quad k_{13} = k_{31} = 0 \tag{15}$$

$$\begin{aligned} k_{22} = {} & R_{load.ref} + R_{\sec.ref} + \\ & + s\left(L_{m.ref} + L_{load.ref} + L_{\sec.ref}\right) \end{aligned} \tag{16}$$

$$\begin{aligned} & k_{23} = k_{32} = \\ & = -\left[R_{load \cdot ref} + R_{\sec.ref} + s\left(L_{load.ref} + L_{\sec.ref}\right)\right] \end{aligned} \tag{17}$$

$$k_{33} = R_{load \cdot ref} + R_{\sec.ref} + R_{tap.ref} + \\ + s\left(L_{load.ref} + L_{\sec.ref} + L_{tap.ref}\right) \tag{18}$$

After Laplace transformation $I_p(s)$ and $I_t(s)$ can be extracted as following. The sum of primary and tertiary current is a short-circuited current in the commutation process through one turned-on switch.

$$I_p(s) = I_{1.pri}(s) \tag{19}$$

$$I_t(s) = I_{3.ter}(s) \tag{20}$$

$$I_{sc}(s) = I_p(s) + I_t(s) \tag{21}$$

Design of OLTC electronic switches depends paramount on the event of short-circuit on secondary side. Coefficient α_5 converts all impedance components in a related circuit on primary side. Short circuit current on secondary side is transfered on HV (primary) side. Through electronic switches will flow the current which is calculated with equation (23):

$$\alpha_5 = \left[\frac{N_t}{MN_m + (K-1)N_t}\right]^2 \tag{22}$$

$$I_{p.sc} = \left| \frac{V_{pt}}{\left[z_{eq} + \left(\dfrac{\alpha_5^2 x_m z_{\sec}}{\alpha_5 \left(x_m + z_{\sec}\right)} \right) \right]} \right| \tag{23}$$

Commutation current is divided into primary and tertiary current according to the model from Figure 2 and for commercial IGBT applications lasts 50 μs [11]. As longer the commutation time is, IGBT has to be designed for standing higher commutation currents. Load impedance and its power factor play a big role in derivation factor of commutation current. Permitted value of the commutation current for the certain IGBT has to be determined in a case with 100 % inductive load.

In the presented model for commutation analysis commutation is considered to occur at a zero crossing current. Accordingly, total leakage inductance is distributed proportionally regarding to the turns ratio on each winding. As presented on the transformer's equivalent model, overlap current is defined as a tertiary current during the commutation between two switches. Since the primary current i_p flows in the same branch as tertiary i_t, resultant of these two is the short circuit current i_{sc} during the commutation process.

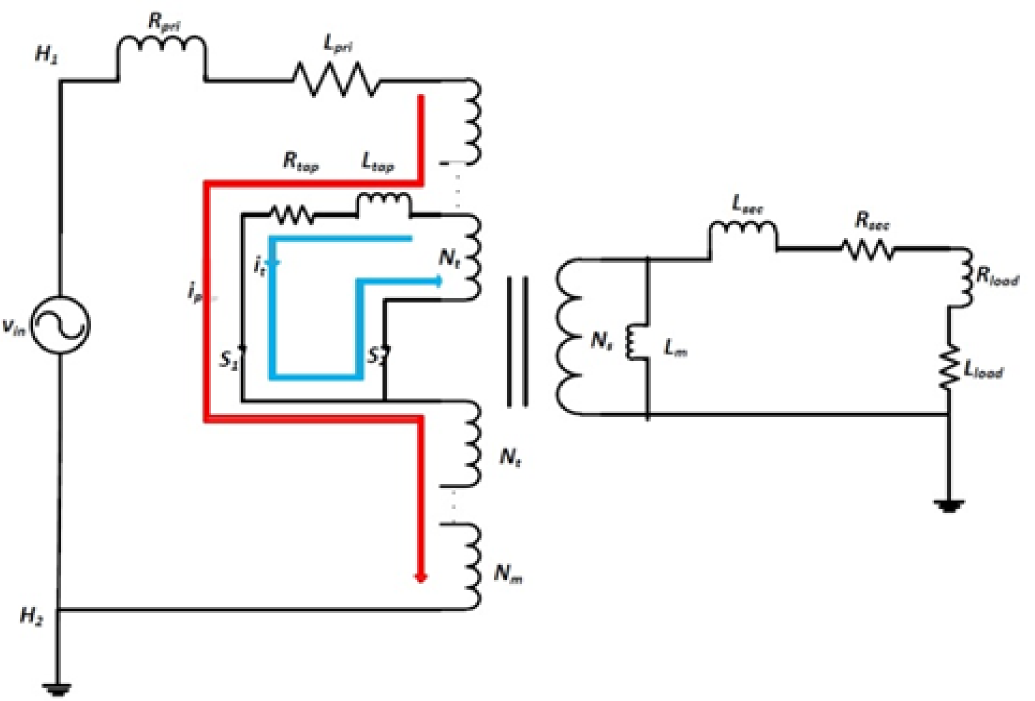

Fig. 2. Currents through the electronic switches during overlap time
(V_{in} – nominal peak primary voltage; R_{eq} and L_{eq} – resistance and inductance of the primary winding disregarding short-circuited tap impedance; R_{sec} and L_{sec} – resistance and inductance of the secondary winding; R_{tap} and L_{tap} – resistance and inductance of the tap ("tertiary") winding; L_m – magnetizing inductance; R_{load} and L_{load} – resistance and inductance of the load)

SOLID-STATE OLTC PROTECTION SYSTEM

Protection system is one of the most important elements of the electronic OLTC since its elements are very vulnerable on feasible overcurrent and overvoltage events which can damage them. Since there is no diverter switch to limit a short-circuit current like in electromechanical tap-changer applications, solid state OLTCs have to deal with extensive commutation currents. Power electronic elements which serve as regulating switches have to have starting circuit, overcurrent, overvoltage, atmospheric discharge and voltage spike protection [12]. Protection system of the electronic switches has to be designed and adopted for operating, as well as for transient and subtransient currents and voltages.

As presented on Figure 3 SCSCP system consists of electromechanical switch R_1 which can handle a permanent short-circuit current. It provides an operation of OLTC during the failure in OLTC circuitry. In the no-load operation R_1 stays closed. This switch is also responsible for protecting electronic switches from inrush current during the start-up process of the transformer [13].

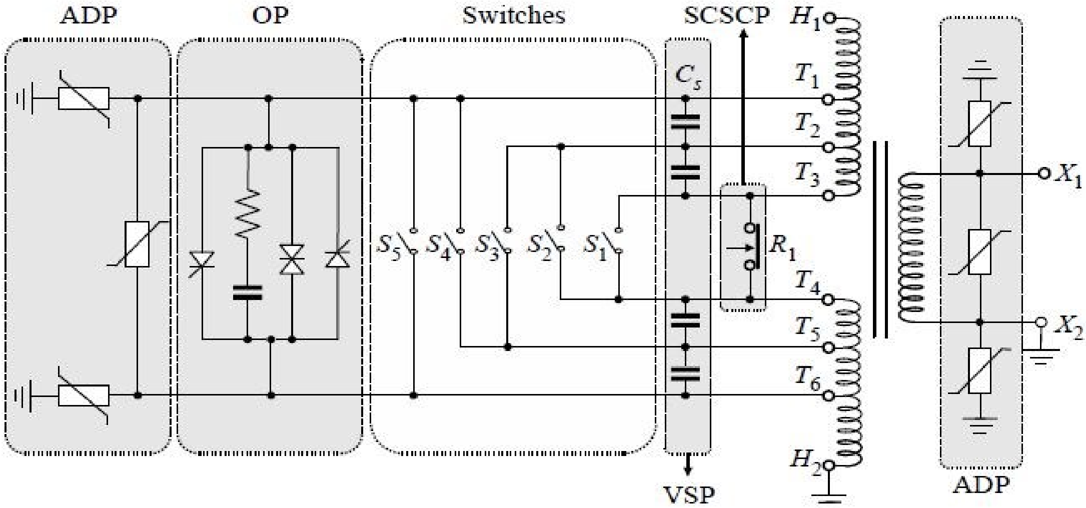

Fig. 3. Solid-state OLTC topology with bidirectional IGBTs and belonging protection circuit (ADP – atmospheric discharge protection, OP – overcurrent and overvoltage protection, SCSCP – starting circuit and short-circuit protection, VSP – voltage spike protection)

Function of the OP crowbar is to protect electronic OLTC against overcurrent and overvoltage events. Thyrisors in a crowbar serve as a redundancy to the electromechanical switch in a case of short circuit or overload current which is determined on 120 % of nominal primary current. Since electromechanical switch R_1 has a longer delay time, thyristors operate first and protect electronic switches from damage. When voltage potential on a crowbar exceeds break oved diode (BOD) level overvoltage protection turns on and prevents overvoltage to appear on IGBT switches.

In addition to the surge arrestors on a primary and secondary side of the transformer, metal-oxide varistors (MOV) are used as an additional protection against atmospheric discharge on a primary as well as on a secondary side.

When a commutation between switches occurs, through the switch which is about to be turned off flows an overlap current. This current results in a stored energy on a tap and may cause the damage if not diverted. Therefor capacitors in parallel with taps are installed to subtract a remained energy across the winding of the turned-off switch. However tap inductance and capacitance of the capacitor in parallel create a resonant LC circuitry and if resistance of a tap is not sufficient to damp oscillations resistor has to be included in such circuitry.

Energy stored in a tap is described by:

$$E_{L_{tap}} = \frac{1}{2} L_{tap} I_{t,overlap}^2 \tag{24}$$

As well as the energy on inductor, only half of the energy on capacitor is stored and the other is dissipated. Energy stored in a capacitor is determined from the next formula:

$$E_{cap} = \frac{1}{2} C_S \left[\left(V_{tap} + \Delta V_c \right)^2 - V_{tap}^2 \right] \tag{25}$$

The maximum peak voltage that occurs on a tap is given by:

$$V_{tap} = \sqrt{2} V_{ps} \left(\frac{N_{tap}}{N_{total} - K N_{tap}} \right) \tag{26}$$

The maximum acceptable voltage across the capacitor ΔV_c is directly related with a maximum acceptable voltage variation on the tap inductance V_{tap} reduced for voltage $\Delta V_{\%}$ which considers to be between 10% and 50% of the V_{tap} in order to protect the damage of electronic switches. There is a compromise between high voltage spike generated on the tap and the circulating current which becomes higher with capacitance C_S:

$$\Delta V_c = V_{tap} \left(\frac{\Delta V_{\%}}{100} \right) \tag{27}$$

By summarizing precedent relations capacitance C_s is given by:

$$C_S = \frac{L_{tap} I_{t.overlap}^2}{\Delta V_c^2 + 2 V_{tap} \Delta V_c} . \tag{28}$$

DETERMINATION OF THE SOLID-STATE SWITCHES AND THEIR PROTECTION SYSTEM

Distribution transformer 20±2×2.5%/0.4 kV, 400 kVA with shown parameters is used for modeling an electronic OLTC.

Table 1

Distribution transformer's winding parameters

Resistance	Ω	Inductance	mH
R_{pri}	4.9395	L_{pri}	132.255
R_{sec}	0.003347	L_{sec}	0.058072
R_{tap}	0.12402	L_{tap}	3.32063
–	–	L_m	138.567
Winding		Number of windings	
$N_m = N_{pri} - 2N_{tap}$		$2310 - 2N_{tap}$	
N_{sec}		28	
N_{tap}		232/4	

The advantage of solid-state type of OLTC is the possibility of applying it in the currently used distribution transformers with voltage regulation in de-energized state. Hence the chosen transformer that is already installed somewhere in distribution network just has to be upgraded with a new voltage regulation. Selected transformer has two main windings ($M = 2$) and four tap windings ($K = 4$). In this case regulation switches are on the primary side as well as on the distribution transformer with DETC. In new distribution transformers with this type of voltage regulation OLTC can be installed on any side of the transformer. Decision is made according to the voltage and current requirements of the power electronic components [14].

Insulated-gate bipolar transistors (IGBTs) are taken into consideration in this article as the electronic switches and are presented as a good future solution in OLTC technology. Though some technical advantages are obvious considering faster switching time and flexibility of switching that give reliability and voltage quality, there are anyway some milestones. Power electronics' sustainability is still not developed to be widely used in distribution network and there are a very few networks that are advanced in that measure where only electronic OLTC would be a suitable solution for a voltage regulation under strict European regulations. The fact is that fully electronic OLTC is not researched enough and is considered still as an unreliable solution. However, it seems as a good voltage regulation technology in advanced distribution networks in not very distant future.

Determination of voltage and current stresses in a normal operation is the first and the main information for selecting electronic switches according to their required operating area.

In a normal operation condition the highest voltage will occur on the switch S_5 when the switch S_1 is turned-on. According to the equation (1) and the transformer parameters voltage across the switch S_5 reaches the value $V_{S5} = 820.03$ V. Therefor selected IGBT has to sustain minimum that voltage. Overvoltage protection system in a crowbar circuitry has to be determined according to the limitation of the BOD (break over diode) on 984 V. Furthermore, since SCSCP's switch R_1 is on the same potential as S_1 it has to withstand the same voltage as the other switching components.

Value of the current through the switches in a state without tap-changing is calculated from the equation (2). The highest possible $I_{S_q} = 15.69$ A occurs when the switch S_5 is turned-on. Overcurrent protection system design in a crowbar circuitry depends on the short circuit current value on the secondary side, transferred to primary. Therefor OP thyristors and electromechanical switch R_1 have to be designed to hold up this current level.

Short circuited tap winding current in the commutation process according to the model on Figure 3 contains primary and tertiary current. Tertiary current flows on the place of the switch which is about to be turned-off. Calculated tertiary current for 100 % load and PF = 0.18 is:

$$I_{t,overlap} = 2.47 \angle 83.24 \text{ A}.$$

Information of the overlap tertiary current is of the huge importance, especially for the capacitor dimensioning in order to subtract the stored energy on the winding after commutation. However, more important information than effective value of the $I_{t,overlap}$ is the behavior of the overlap current during the certain period of time. Diagram on the Figure 4 shows the overlap current in dependence of the load factor over the time.

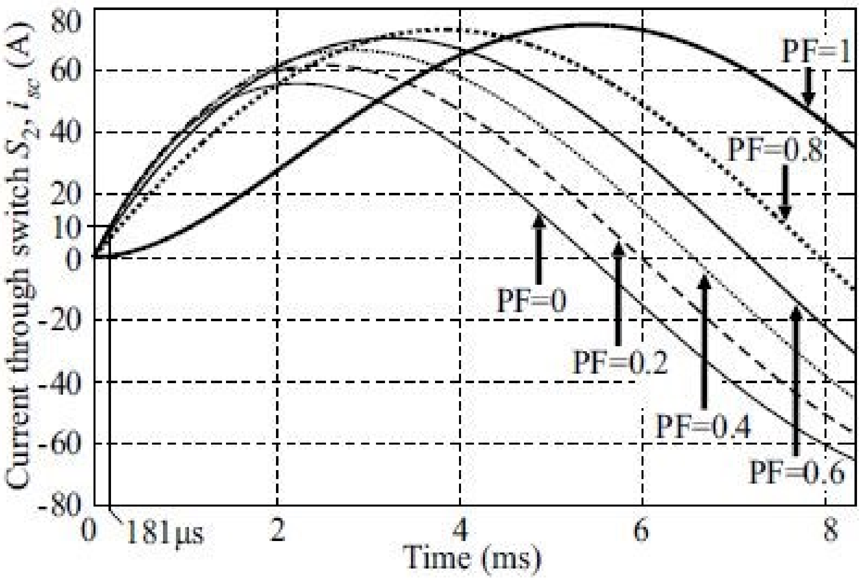

Fig. 4. An example of the overlap current characteristic on the switch in dependence with power factor (PF)

VSP capacitors are responsible for subtraction of the energy from exited winding. Calculation of capacitance of the VSP depends on the overlap current. Since overlap current depends significantly on the load power factor, acceptable overlap time has to be taken for the worst case. Worst case is when the load is completely inductive (PF = 0). Permitted overlap time has to be checked according to the chosen operating current level of the electronic switch. If the overlap time of the IGBTs is less than the maximum acceptable overlap time for fully inductive load, there is no problem in such application.

CONCLUSION

In this paper a technology of a solid-state OLTC in a distribution transformer is discussed with all its advantages and disadvantages. Advantages like fast switching time from one to any other tap, no arc, no movable parts, less size etc. over currently used electromechanical tap-changers are presented. Electromechanical switching method is major nowadays and the only commercial choice because of its undeniable reliability and low price, but disadvantages like slow and limited switching operation as well as causing flickers could be a drawback in a future smart-grid.

Calculation model for the electronic components in OLTC gives the methodology for determination of the electronic switches and protection circuit design. Currents and voltage values for steady and commutation state are calculated according to the parameters of one distribution transformer with DETC. Results determine the mandatory design, size and price of the electronic switches as well as protection system components.

Renewable energy resource as the most significant energy producer causes the problem with voltage regulation. Highly autonomous networks with energy produced mostly in a distribution network and strict regulations of the voltage quality are the big challenge for conventional electromechanical OLTCs with slow voltage regulation response [15]. Therefor solid-state OLTC technology has an objective potential to become widely used in a close future.

REFERENCES

[1] Benz, T.: *Smart Grids: Erfahrungen mit Pilotprojekte*n, VDE-Arbeitskreis Elektrotechnik, München, Germany, 2013.

[2] Dohnal, D.: *On-Load Tap-Changers for Power Transformers*, Maschinenfabrik Reinhausen GmbH, Regensburg, Germany, 2013.

[3] Chen, N., Jonsson L., E.: A New Hybrid Power Electronics On-load Tap Changer for Power Transformers, *IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2015.

[4] Faiz, J., Siahkolah, B.: New Solid-State Onload Tap-Changers Topology for Distribution Transformers, *IEEE Transactions on Power Delivery*, **18**, 1, 136–141 (2003).

[5] ABB Schweiz AG: UNITROL® 1000 Automatische Spannungsregler AVR Kompakt und Leistungsfähig, Turgi, Switzerland, 2012.

[6] Kabiri, R., Holmes, D. G., McGrath, B. P., Meegahapola L. G.: LV Grid Voltage Regulation using Transformer Electronic Tap Changing, with PV Inverter Reactive Power Injection, *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 2014 (JESTPE-2014-11-0304.R2 1).

[7] Zhou, Hui; Zhang, Wei; Xinghau, Wu: Optimization of Reactive Power for Active Distribution Network with Power Electronic Transformer, *IEEE European Energy Market (EEM),* 2015.

[8] Kandula, R. P., Chen, H.., Prasai, A.., Lambert, F.: Field Upgradeable Transformer: A Fractionally-Rated Voltage Regulator for the Distribution System, I*EEE Energy Conversion Congress and Exposition (ECCE*), 2016.

[9] Faiz, J., Siahkolah, B.: Solid-state tap-changer of transformers: Design, control and implementation, *Elsevier International Journal of Electrical Power & Energy Systems*, **33**, 2011.

[10] De Oliveira Quewedo, J.: Analysis and Design of an Electronic On-Load Tap Changer Distribution Transformer for Automatic Voltage Regulation, *IEEE Transactions on Industrial Electronics*, 2017.

[11] De Oliveira Quevedo, J., Giacomini, J. C.: Smart Distribution Transformer Applied to Smart Grids, *IEEE Power Electronics Conference (COBEP)*, 2013.

[12] Abbaszadeh, K., Ardebili, M., Alaei, A. R.: Design and Built of on - Load Fully Electronic Tap-Changer with Triac Switch: Simulation and Practical Results, *IEEE Power Electronic & Drive Systems & Technologies Conference (PEDSTC)*, 2010.

[13] Faiz, J., Siahkolah, B.: Optimal configurations for taps of windings and power electronic switches in electronic tap-changers, *IET Proceedings – Generation*, *Transmission and Distribution*, Vol.: **149**, Iss.: 5 (2002).

[14] Mailah, N. F., Bashi, S. M., Meng, W. H.: Microcontroller Based Semiconductor Tap Changer for Power Transformer, *IEEE Power Tech Conference Proceedings*, 2003.

[15] Aly, M. M., Abdel-Akher, M., Ziadi, Z., Senjyu, T.: Assessment of reactive power contribution of photovoltaic energy systems on voltage profile and stability of distribution systems, *Elsevier International Journal of Electrical Power & Energy Systems* **61**, pp 665–672 (2014).