TAP CHANGER POSITION DETERMINATION USING NEW ALGORITHM AND POSSIBILITIES OF INTELLIGENT ELECTRONIC DEVICES

Siniša SPREMIĆ
EPS-P.D. Elektrovojvodina - Serbia
sinisa.spremic@ev.rs

Mileta SENTIN
EPS-P.D. Elektrovojvodina - Serbia
mileta.sentin@ev.rs

Dušan PETROVIĆ
EPS-P.D. Elektrovojvodina - Serbia
dusan.petrovic@su.ev.rs

Zoran RISTANOVIĆ
Energotehnika Južna Bačka - Serbia
zoran.ristanovic@entjuba.rs

ABSTRACT

Paper consider possibility for determining On-Load Tap Changer (in following text: OLTC) position using primary and secondary (tertiary) currents and voltages of transformers equipped with OLTC. New algorithm for OLTC position determination using primary and secondary (tertiary) currents and voltages is presented. Different influences on algorithm accuracy like analog inputs errors of Intelligent Electronic Devices (in following text: IED), transformer turn ratio errors, instrument transformers accuracy errors, errors due to magnetizing (no load) currents and voltage drop were considered. Results of practical check are given in order to prove applicability with aim to improve reliability in particular segments of electricity distribution: automation, protection and control (supervision).

INTRODUCTION

Modern IEDs for transformers protection incorporate all necessary protection and automation functions and signaling. They are programming devices so it is possible to make additional protection, automation and control functions and signaling or existent could be expand in order to improve existent functions and reliability and to make new functions using communication possibilities. OLTC position data is necessary for local and remote supervision purposes, for parallel operation of transformers using master-follower method and could be used for more sensitive adjustment of differential protection. Existent OLTC position data is obtained from OLTC`s motor drive unit using different types of output. Possible outputs are resistance, mA (more common) or V (less common), contact range and codes (BCD, Grey and Binary). Those devices are reliable but sometimes different malfunctions occur. Mechanical, electrical, chemical and electromechanical malfunctions like broken parts, bad contact, rust, stain, etc. lead to false or no OLTC position data which will cause blocking of parallel operation of transformers using master-follower method and to less sensitive differential protection in IEDs which have this option. Less important but not negligible is missing remote supervision data. One of nowadays trends is reliability improvement in every segment of electricity distribution. Using advanced possibilities of modern IEDs and new algorithm for OLTC position determination using primary and secondary (tertiary) currents and voltages could improve reliability.

ERRORS OF OLTC POSITION DETERMINATION USING CURRENTS

Errors of OLTC position determination using currents in new algorithm are analog inputs errors of IED, transformer turn ratio errors, current transformers accuracy errors and errors due to magnetizing (no load) currents of transformers.

Absolute values of errors for current analog inputs in IEDs are less than 1 %, mostly lower than 0,5 % up to I_n.

Turn ratio errors of transformers are limited by standard [1] and should be in ±0,5 %. According to test reports of transformers, measured values of turn ratios are significantly lower than 0,5 % and they are similar among phases.

Current transformers accuracy classes at 110 kV side are 0,2 % or 0,5 %. At low voltage side accuracy class is mostly 1 %. Phase class is negligible for this consideration (up to 30 min). Accuracy errors according to test reports are significantly lower than accuracy class at nominal current and power factor 0,8. Current transformer producers during designing and producing made certain correction in order to shift accuracy curve with positive error at higher loads and negative at lower loads.

Most interesting are errors due to magnetizing (no load) currents. No load currents depend of design and materials used in transformer production [2]. Older transformers 110/x kV with poorer quality of steel sheets have no load currents from 1 % to 3 % of nominal current of transformer and newer from 0,2 % to 0,5 % at U_n. No load currents have significant increase with voltage increase. Voltage increase of 10 % lead to increase of no load currents mostly up to 4 %. No load currents among phases could be significantly different due to core construction. This is the reason to use all phase currents to calculate turn ratio and thus OLTC position. Using results of no load loss and current measurements for several transformers, calculation was made in order to check level of error originated from no load currents. Secondary voltage values are set to $0{,}9U_n$, U_n and $1{,}1U_n$ for load range from 10 % to 100 % and for values of power factor (0,8 – 0,85 – 0,9 – 0,95 – 1). Results for one of considered transformers 110/x kV with low level of no load currents are given in Figures 1, 2 and 3.

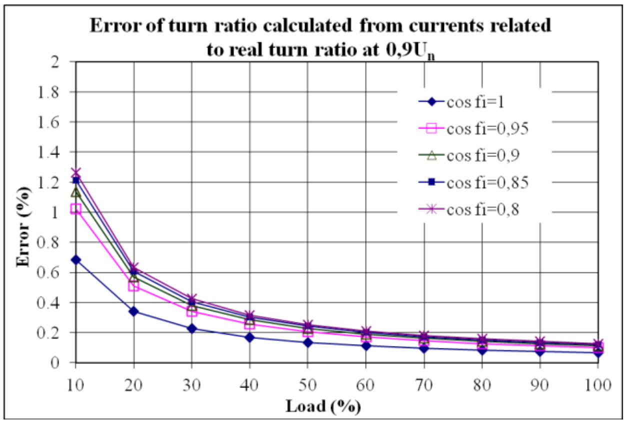

Fig. 1 Error characteristics at $0{,}9U_n$

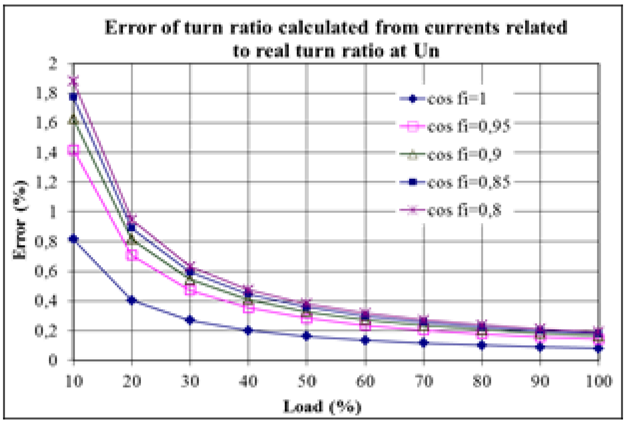

Fig. 2 Error characteristics at U_n

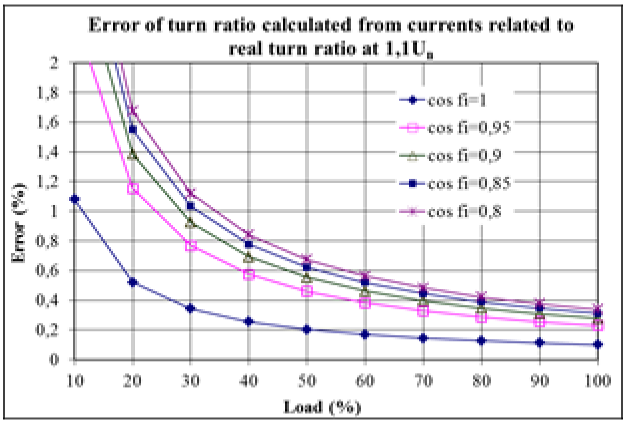

Fig. 3 Error characteristics at $1{,}1U_n$

Figures 1, 2 and 3 show that error originated from magnetizing (no load) currents have tendency of increase in cases od decreasing load and power factor value and increasing voltage. U_n of considered transformers is 21 kV and normal operating voltages are in range from 20 kV to 21 kV, power factor values are in range from 0,92 to 0,98 and loads which have significant daily or season changes are mostly greater than 30 %. It can be assumed that error of magnetizing currents at normal operating conditions should be less than 0,6 % which is less than 0,4 position for voltage step of 1,6 %.

ERRORS OF OLTC POSITION DETERMINATION USING VOLTAGES

Errors of OLTC determination using voltages in new algorithm are analog inputs errors of IED, transformer turn ratio errors, voltage transformers accuracy errors, errors due to load currents of transformers and load asymmetry among phases and error of parallel operation of transformers.

Absolute values of errors for voltage analog inputs in IEDs are less than 1 %, mostly lower than 0,5 %.

Turn ratio errors of transformers are limited by standard [1] and should be in ±0,5 %. According to test reports of transformers, measured values of turn ratios are significantly lower than 0,5 % and they are similar among phases.

Voltage transformers accuracy classes at 110 kV side are 0,2 % or 0,5 % [3, 4]. At low voltage side accuracy class is mostly 1 % [3, 4]. Phase class is negligible for this consideration (up to 30 min). Accuracy errors according to test report are significantly lower than accuracy class at nominal voltage.

Symmetrical or asymmetrical load currents have the greatest influence in OLTC position determination using primary and secondary voltages. Voltage drop in transformer impedance which is mostly reactance have significant values at normal operating conditions.

Figure 4 shows difference of calculated and set (real) OLTC position using voltage drop calculation for considered transformer.

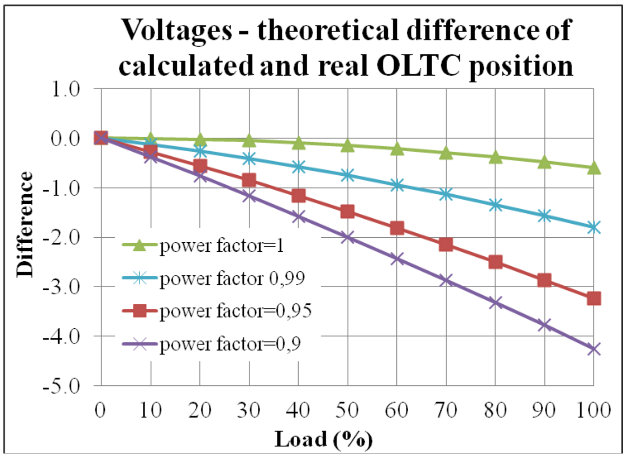

Fig. 4 Difference of calculated and real OLTC position

It is obvious that voltage drop and difference of calculated and set (real) position have low value at power factor cosφ=1 and difference has significant value even for power factor cosφ=0,99.

OLTC position determination using voltages of paralleled transformers is not possible because transformers have same primary and secondary voltages no matter of actual positions of paralleled transformers. Because of that it is not possible to determine accurate OLTC position using new algorithm from voltages in case of parallel operation of transformers.

NEW ALGORITHM FOR OLTC POSITION DETERMINATION

OLTC position determination using primary and secondary (tertiary) currents and voltages need certain prerequisites. In order to simplify consideration only primary and secondary currents and voltages will be considered. It is necessary to set some parameters at IED. Those parameters are nominal turn ratio m_{12sr}, step voltage V_s (%) and overal number of positions with different turn ratio n_{uk} (transition positions and positions without turn ratio change are exluded). IEDs should have analog inputs for all three primary and secondary currents and voltages. New algorithm is given in following equation

$$n_{RS} = n_{uk} - \frac{m_{meas} - m_{12sr}\cdot\left(1-\frac{V_s}{100}\cdot\left(\frac{n_{uk}-1}{2}\right)\right)}{m_{12sr}\cdot\frac{V_s}{100}} \quad (1)$$

or in simplified form

$$n_{RS} = \frac{100}{V_s}\cdot\left(1-\frac{m_{meas}}{m_{12sr}}\right) + 0{,}5\cdot n_{uk} + 0{,}5 \quad (2)$$

Equation for calculated turn ratio from primary and secondary currents m_{meas} is

$$m_{meas} = \frac{I_{L1\sec} + I_{L2\sec} + I_{L3\sec}}{I_{L1prim} + I_{L2prim} + I_{L3prim}} \quad (3)$$

or from primary and secondary voltages m_{meas} is

$$m_{meas} = \frac{U_{L1prim} + U_{L2prim} + U_{L3prim}}{U_{L1\sec} + U_{L2\sec} + U_{L3\sec}} \quad (4)$$

Calculated („measured“) OLTC position n_{RS} using new algorithm shall be rounded to integer value. Using averaged value of currents or voltages at certain period (e.g. several sine periods) is the way to use algortihm. Because of faults in supplied network or at opposite side of the transformer there is possibility that high values of currents or sudden voltage changes occur. This could lead to higher level of accuracy errors at particular periods of time. Increased accuracy errors is the reason to ignore this periods. This will not cause any malfunction because faults with high currents should be disconnected by protecting devices very fast and automatic voltage regulation is slow procedure compared to protection functions. Whole process of OLTC position change, depending of type of OLTC, lasts from 2 to 7 seconds so exluding some periods will not cause reliability decrease. Higher voltage drop, depending on parameters set at automatic voltage regulator, will cause that automatic voltage regulator block OLTC operation so calculated OLTC position prior to blocking will be in use.

PRACTICAL CHECK OF NEW ALGORTHM

In order to prove applicability of proposed algorithm practical check was made. Several different transformers 110/21/10,5 kV/kV/kV and 110/36,75/10,5 kV/kV/kV with nominal power of 31,5 and 20 MVA and step voltage 1,6 % and 1,5 % were checked. Transformers have IED units of three different producers.

Power factor values were within range of 0,93 to 0,99. Primary voltages were within range of 108 kV to 116,9 kV. Secondary voltages were within ranges of 19,9 kV to 21,17 kV and 35,14 kV to 36,09 kV. Whole OLTC position range is from 1 to 21 and for practical check it was from 6 to 21.

Figure 5 shows difference of “measured” OLTC position using currents and real OLTC position. All differences are less than 0,5 so rounded value of “measured” OLTC position will be equal to real OLTC position.

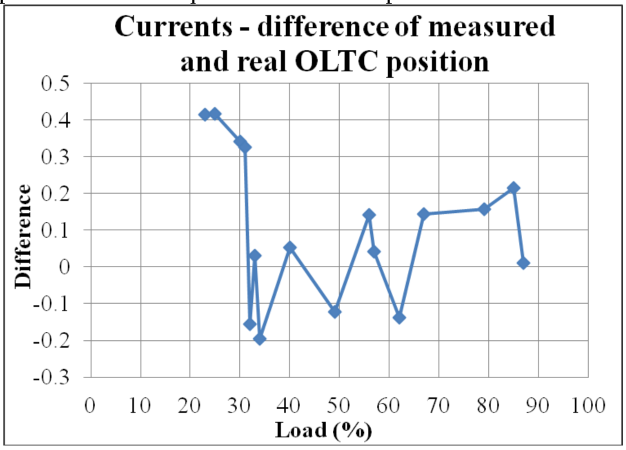

Fig. 5 Difference of measured and real OLTC position

Figure 6 shows difference of “measured” OLTC position using voltages and real OLTC position. One phase to phase voltage was used in calculation instead all three phase voltages. Load increasing lead to OLTC position difference increasing similar to characteristics from Figure 4. Up to about 30 % of load difference of “measured” to real OLTC position is less than 0,5 so rounded OLTC position will be equal to real.

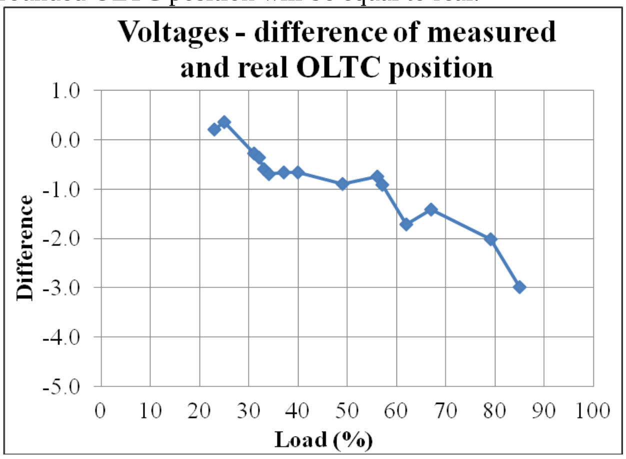

Fig. 6 Difference of measured and real OLTC position

Addition of all errors for currents could give overall error of about 5 % which is in case of step voltage of 1,6 % more than 3 OLTC positions error. Some of errors compensate each other. For example current transformers usually have positive error at currents from $0{,}25I_n$ to $1{,}2I_n$. Current transformer of low voltage side of the transformer are of lower accuracy class than current transformers of high voltage side so it is expected that ratio I_{sec}/I_{prim} has positive error. Contrary influence of magnetizing currents have negative influence at whole range of currents for ratio I_{sec}/I_{prim} so current transformer error is compensated with magnetizing current influence. It is possible that other errors compensate each other at certain level.

Practical check at load range from about 20 % and 90 % shows applicability of proposed algorithm for OLTC position calculation using measured primary and secondary currents and voltages.

Currents usage shows good results at range from 20 % to about 90 % of load. It could be expected that current could be used for loads up to 120 % and possibly more.

Voltage usage shows good results at range from 0 % up to about 30 % of load.

Hitherto practical checks lead to recommendation to use voltages up to 20 % of load and currents from 20 % upward for OLTC position calculation.

It is necessary to make additional numerous practical checks in order to prove applicability at loads lower than 20 % and greater than 90 % and to check range from 20 % to 30 % of load. Range from 20 % to 30 % of load is boundary area in which average value of OLTC position determined from currents and voltages could be the best option to use.

ALGORITHM APPLICABILITY

OLTC position determination using proposed algorithm could be applied for:

- Basic OLTC position data in case of old motor drive units with inoperable device for OLTC position without possibility to simple repair or change.
- Spare OLTC position data in case of malfunction of device for basic OLTC position data useful for local and remote supervision purposes and for parallel operation of transformers using master-follower method avoiding parallel operation blocking. Even in case of one or two real OLTC position difference among paralleled transformers because of errors in measuring chain there will be no parallel operation blocking. Parallel operation blocking is undesirable because it could lead to big voltage fluctuations.
- Control (supervision) OLTC position data in case of non reliable data from OLTC position device due to contact problem (rust, stain).
- Differential protection could be set more sensitive using OLTC position data. For example if current transformers on both sides are rated 5P10 (i.e. composite error is max. 5 %) and the OLTC range is ±10x1,6 % calculate starting ratio setting S = 5 % (HV CT) + 5 % (LV CT) + 10x1,6 % (OLTC) + 4 % (relay) + 5 % (margin) = 35 %. If OLTC influence should be compensated automatically starting ratio setting S = 5 % (HV CT) + 5 % (LV CT) + 4 % (relay) + 5 % (margin) = 19 % which is significantly lower than without compensation. If we include margin of OLTC position error obtained with algorithm of two positions starting ratio setting will be S = 5 % (HV CT) + 5 % (LV CT) + 2x1,6 % (OLTC) + 4 % (relay) + 5 % (margin) = 22,2 % which is also significantly lower than value in first calculation. There is no need for analogue input for OLTC position in IEDs.

Even if IED has not got analogue inputs for all voltages and currents it could receive data using IEC 61850 or other protocol communication. Received data must be synchronized with data obtained by IED`s analogue inputs to avoid calculation errors of data from different time periods.

CONCLUSION

Proposed algorithm for OLTC position determination is simple and applicable in modern IEDs. It could improve reliability in small but relevant segment of automation, e.g. parallel operation of transformers using mater-follower method avoiding parallel operation blocking in case malfunction of device for OLTC position data. It is applicable in protection improving sensitivity of differential protection without need for analogue input or inputs for OLTC position data. It is also useful for basic, spare or supervision OLTC position data in case of malfunction of device for basic OLTC position data.

Further consideration will comprise numerous practical checks in order to test whole range of loads with attention on range from 20 % to 30 % of load as boundary between good results of OLTC position determined from measured voltages or currents and to review correction possibilities.

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