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Using Data from SCADA for Centralized Transformer Monitoring Applications

Domagoj Peharda[a]*, Igor Ivanković[b], Nikola Jaman[b]

[a]*Končar-KET, Fallerovo šetalište 22, 10000 Zagreb, Croatia*
[b]*Croatian Transmission System Operator-HOPS, Kupska 4, 10000 Zagreb, Croatia*

Abstract

Modern Supervisory Control and Data Acquisition (SCADA) systems collect any available data from the systems they monitor and control. Some of the data available in modern SCADA systems include types of the data that can be used for centralized monitoring of transformers. Paper presents possible advanced analysis and reports for monitored transformer units using available SCADA data to be used for monitoring of the life of the transformer and help to schedule regular, predictive and corrective types of maintenance. Paper shows which type of data is available, and what percentage of transformers has the kind of data used for monitoring. Examples of measurement data collected is shown for representative transformers. There is an overview on tap changer position moves and its impact on transformer lifetime and servicing interval. For transformers with available temperature of winding an annualized relative ageing rate is calculated.

Keywords: SCADA; transformer monitoring; transformer health; centralized monitoring; asset management

1. Introduction

Advancement in telecommunications and computing in modern Supervisory Control and Data Acquisition (SCADA) systems allow for collection of any available data from the systems they monitor and control [1]. This diverse data are, beside the main monitoring and control functions, used in smart grid transmission control centers by many advanced tools and applications [1][2]. Some of the data available in modern SCADA systems include types of the data that can be used for centralized monitoring of transformers. Transformer unit in transmission

* Corresponding author. Tel.: +385-99-8138-601; fax: +385-1-3667-515.
E-mail address: domagoj.peharda@koncar-ket.hr

network is a crucial and expensive element, often unique and hard to replace. All of those are the reasons that careful attention must be provided for transformer during its lifetime.

Monitoring systems for large power transformers are widely used at transmission system operators and at power plants [3] [4] [5] [6] [7] [8] [9] [10]. These systems are mostly tailored made for specific power transformer and have complex specifications and design [11] [12]. Monitoring system tracks power transformer status using three major monitoring types: current monitoring [13], overvoltage monitoring and gas analyses. Last two monitoring types have to have additional equipment placed on a transformer tank. This equipment is necessary to trace complex events caused by overvoltage (atmosphere or switching) and oil – gas relations.

Task of monitoring power transformers based on current measurements can be shifted to a SCADA system in control center because current or power and voltage measurements from most of power transformers come to SCADA. Using SCADA most of the transformers at transmission system level and at power plants can be monitored, which can be very valuable for asset management. Current monitoring can be extended with other data from SCADA database, like oil and winding temperature [14], number of operating hours (days) in a year, number of tap changer operations, and some other signals.

SCADA database contribute to transformer monitoring in a specific way. Data are available continuously and a report can be easily and automatically generated for a period of a week, a month or a year, for several years in the past. Data collected by SCADA contains valuable information for planning and maintenance procedures of power transformers, especially when customer or owner do not have a classic monitoring system.

2. Data Available in SCADA System of Power Transmission System Control Center

2.1. Network Model in SCADA System

Signals and measurements that come into SCADA system in power transmission system control centers are attached to the energy management system (EMS) network model. This network model represents stations, lines, generators, transformers, buses, and other elements needed for various EMS calculation. The EMS network model contains topology information connecting signals and measurements to elements in the network model. The EMS network model contains also various parameters on elements describing types of transformers, rated power and voltage, location and type of tap regulation, and other useful information. Parameters and placement of transformers are used for putting signals in measurement in context (e.g. getting maximum value for current from rated power and voltage) and for classification of types of transformers. Transformers can be classified using different criteria: ownership, voltage levels, rated power, type of winding, function, etc.

The EMS network model must also contain neighboring elements which are not owned nor maintained by transmission company even though they are supervised. This paper will show a possibility for centralized monitoring for both owned assets and just supervised transformers.

In the whole EMS network model there are 543 transformers, of which 350 are power transformers owned by transmission system operator (TSO) or distribution system operator (DSO), 76 are supervised auxiliary transformers (other transformers not used for transmission or distribution), 100 transformers are in external network, and 17 are owned by supervised power plants which can be seen in the table 1.

Table 1 Number of transformers in the EMS network model

	110/x kV	220 kV and 400 kV	Total
(TSO+DSO) operating assets	308	42	350
External	29	71	100
Other	73	3	76
Production	10	7	17
Total	420	123	543

2.2. Measurements Acquired by SCADA System

Primary function of SCADA system in transmission system control centers is to ensure secure operation of the power system. To perform this task a lot of information is gathered in real time. Not all of this information is recorded for permanent storage. Time resolution and retention periods are configured according to the law and capabilities of the hardware. In SCADA system from which data were gathered for this paper, smallest time resolution for non-crucial measurements is 10 seconds. For purpose of this paper averages of the measurements over 15 minutes period were used during first 8 months of 2016.

SCADA system collects a lot of types of data. Following types of data topologically related to the transformers are available:

- Measurement of transformer temperatures
  - Winding temperature,
  - Oil temperature,
- Measurement of transformer loading;
  - Voltage measurement,
  - Active and reactive power,
  - Current measurement,
- Number of working hours,
- Tap changer operations.

This paper aims to show examples of these data for several types of transformers.

Transmission system operator in Croatia have used 2165 measurements from transformer and topologically connected bays with 38 million measurement values (15-min average values) for all owned and maintained power transformer.

Table 2 Measurements used for TSO+DSO owned transformers according to a measurement unit

	In % of transformers	Number of measurement
MW	90%	424
Mvar	89%	421
Tap changer position	83%	298
MVA	63%	250
kV	48%	242
A	39%	340
Temperature of oil and winding	16%	69
Other	-	121
Total		2165

2.3. Signals Acquired by SCADA systems

Numerous signals were collected directly from transformer unit and from devices in transformer high voltage and low voltage bay. TSO SCADA gathers all or most of signals coming from TSO owned transformer unit. From transformers belonging to other companies signals that are arriving in SCADA in TSO control center do not have information on transformer health, but only on operation status.

Signals coming from TSO owned transformer units:

- Temperature warnings and alarms,

- Buchholz relay operations,
- Thermal picture,
- Transformer cooling system (fans, oil pumps, and other related signals),
- Oil monitoring,
- Oil level, moisture level, oil separator, etc.,
- Various protection signal (overcurrent, differential, thermal, REF function, etc.)

Table 3. presents top 10 signals which originate in transformer itself. Some of these events signal the need for immediate response and others a need for increased maintenance.

Table 3. Top 10 signals coming from transformers

Name	In % of transformers	Number of signals
Buchholz trip	73%	254
Buchholz warning	68%	237
OLTC protective relay	51%	180
Oil thermometer trip	49%	173
Oil thermometer warning	48%	167
Differential protection	44%	153
Differential overcurrent	33%	116
Pressure relief valve	33%	115
Differential instantaneous overcurrent	33%	115
Winding thermometer trip	31%	109

Faults where fault current or overvoltages influence transformers, must also be considered as transformer health indicators. Short circuit in the vicinity of transformer creates strong radial and axial forces on all windings. Cumulative of faults that happen near transformers can have an impact on maintenance and life of the transformer. This is the reason to monitor certain types of faults in a substation [3].

Table 4. Top 5 protection signals coming from bays topologically connected to the transformer

Name	In % of transformers	Count
Overcurrent protection	68%	645
Instantaneous Overcurrent protection	45%	274
Thermal protection	29%	124
Trip coil supervision	41%	182
Restricted Earth Fault Protection	24%	103

Signals were not used for calculation of transformer health because currently it is not possible to distinguish between maintenance and actual fault signals.

3. Transformer lifetime indicators

3.1. Transformer temperature footprint

Out of 350 transformers owned and maintained there are 52 measurement of temperature of the winding and 71 measurement of temperature of the oil brought to the SCADA system in the control center. 173 alarm and 167 warning signals for the temperature of oil are brought to the SCADA system. As an example, charts from representative transformers units will be shown in following figures.

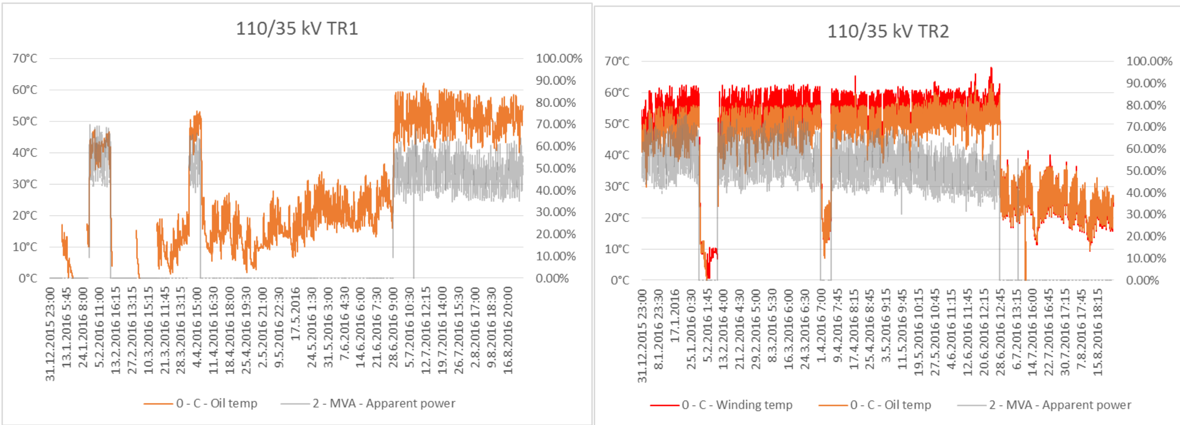

Fig. 1. Temperature and power (in percentage of rated power) for distribution transformers in the same station (a) transformer 1; (b) transformer 2

In the supervised network considered in this paper the largest number of transformer unit are installed on TSO-DSO interconnection. These consist of 110/x kV units which have commonly two units per substation in order to fulfill obligations on reliability of supply. Those units usually alternate in operation as can be seen in Fig. 1 where charts are shown for two transformers in the same substation. Three values were traced, apparent power, oil and winding temperature. Units were loaded from 40% to 60% of nominal power during observed period.

Transformer unit 1 is of older type which has no measurement of winding temperature and it is shown on Fig. 1. (a). Newer unit with both winding temperature and oil temperature measurement is shown on Fig. 2. (b). During operation, cooling system keeps the temperature under the set limit, whereas while the transformer is off-line, temperature reflects the environment temperature.

Large power transformer units are very important for TSO. An example of a 400/110 kV transformer with nominal power of 300 MVA is shown in Fig. 2. (a). It is shown that this unit has low loading (because of security considerations it is in parallel operation with another 400/110 kV transformer). Temperature of this transformer rarely reaches set temperature for cooling system.

Step-up transformer that is connecting wind power plants to the grid is shown in Fig. 2. (b). Intermittent nature of the wind power is clearly visible in the chart.

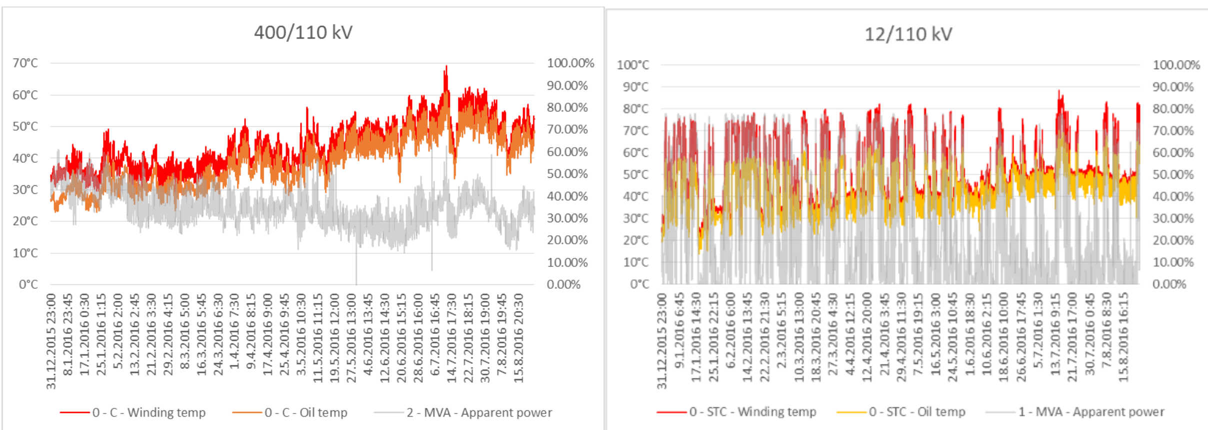

Fig. 2. (a) winding and oil temperature of power transformer 400/110 kV; (b) winding and oil temperature of step up power transformer 12/110 kV in a wind plant

3.2. Transformer working hours

National regulatory body and ENTSO-E (European TSO for electricity) created mid and long term planning obligations for TSO. Operated working hours for transformer unit give some information particularly for long term planning procedures. Also for the purpose of the mid-term planning procedure on substations level it is possible to distribute operation between few units.

Number of working hours is calculated using active power measurement whenever it is greater than zero. Most transformers are in redundant configuration where usually only one is in operation, which is the reason a lot of transformers have been in operation for less than 100% of the time. Working hours for TSO+DSO operating transformers during period of 5472 hours is presented in Fig. 4.

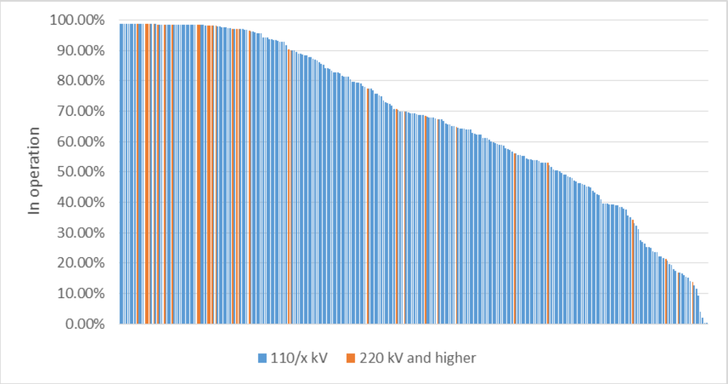

Fig. 3. Percentage of hours in operation of the total period considered for TSO+DSO transformers

Another indication for transformer lifetime is a number of transformer energization. Currently it is not possible to determine the number of transformer energization from the data that are collected.

3.3. On load tap change position footprint

On load tap changer position change statistics should be recorded and analyzed because statistically more than third of transformers between 100 kV and 200 kV had failures on tap changers. This also allows for modification of maintenance procedures and optimal transformer maintenance schedule.

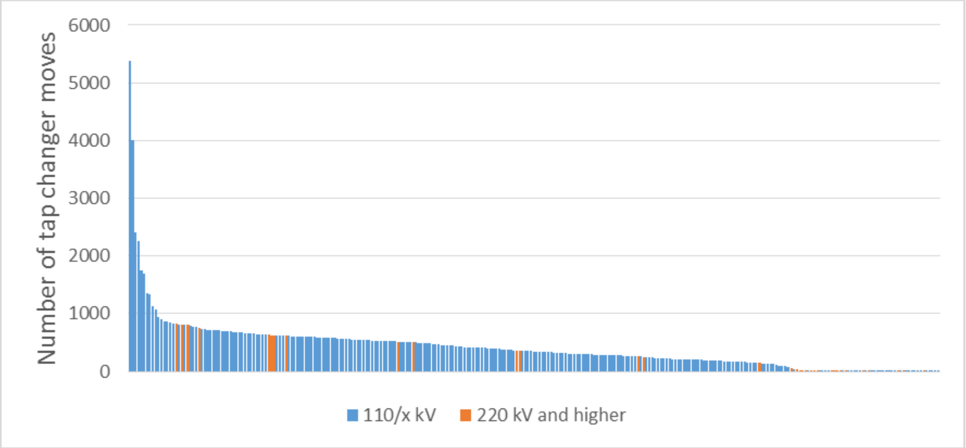

Fig. 4. Number of moves of tap changer during first 8 months of 2016 per transformer (281 transformer units)

Figure 4 shows three different groups of transformers. Small number of 110/x kV transformers have more than 4 tap changing actions per day (observed in 228 days) which are caused by lack of voltage controllers on some 400/110 kV and 220/110 kV transformers. This figure should indicate where increased maintenance of tap changers is required.

Data gathered on tap changer position moves can be used for other TSO business processes. Most of TSO transformers in operation have installed on line tap changer (OLTC) with automatic voltage regulation (AVR). It is possible to utilize large transformer units to regulate 110 kV network in narrow voltage boundaries, which lowers the number of tap changer position moves in 110/x kV transformers (see difference between Fig. 5. and Fig. 6.). 110/x transformers are more numerous and resulting reduction in maintenance of 110/x kV transformers' tap changers lowers the overall maintenance cost.

Older transformers do not have a capability of automatic voltage regulation, and in those regions values in 110 kV network have more oscillations and its regions' 110/x kV tap changers operated more frequently which is visible in Fig. 6.

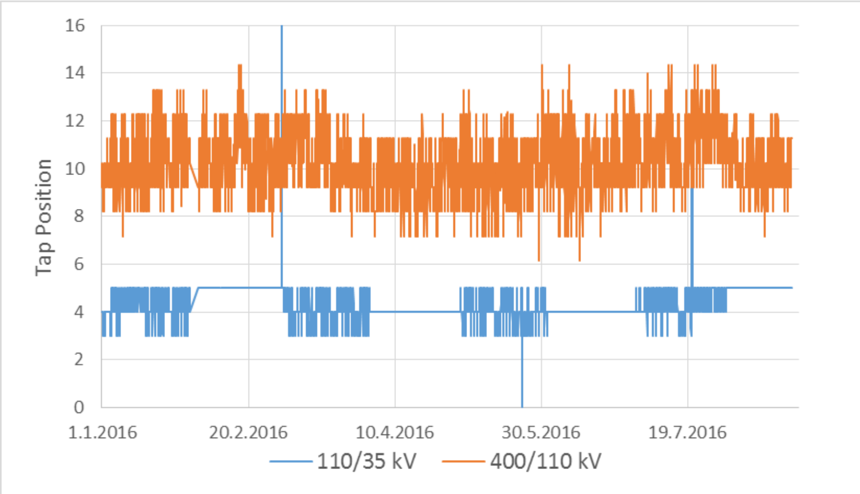

Fig. 5. Tap changer position during first 8 months of 2016 in a region where 110 kV voltage level is regulated by automatic voltage controller on 400/110 kV transformers

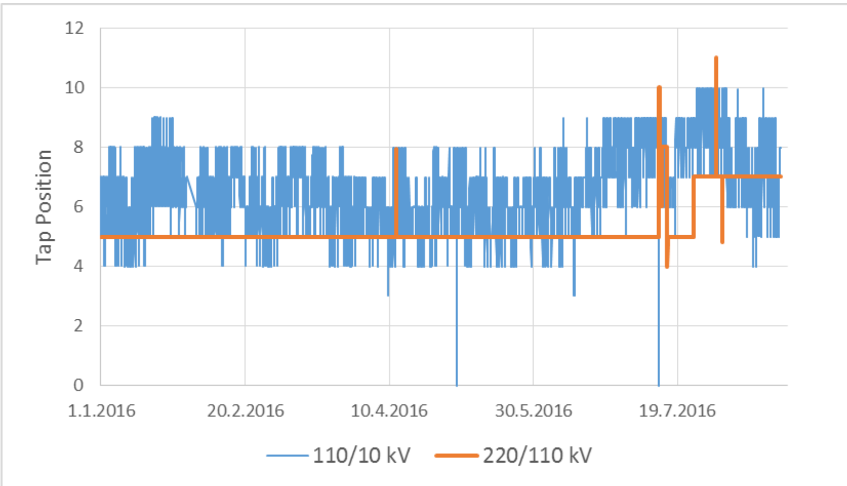

Fig. 6. Tap changer position during first 8 months of 2016 for a transformer in a region where tap position on 400/110 kV and 220/110 kV transformers is set manually

OLTC manufacturers have proscribed procedures for maintenance of its equipment which utilities usually follow. Manufacturers proscribe to service tap changes every few years or after certain number of operations. Number of operations between servicing ranges from 25.000 and 50.000 which depends on manufacturer and type. The tap changer position movement (operations) data can be used for finding deviations in OLTC operations when action can be taken to restore to normal OLTC pattern of operation. Also these data can be used for tuning of parameters of AVR.

4. Relative Ageing Rate

The lifetime of the transformer paper insulation depends on age, temperature of the winding during its lifetime, moisture, oxygen and acid content [15]. One of key indicators for the life expectancy of the transformer is measured temperature in the transformer. These values are continuously measured by SCADA. The best choice for this indicator is an actual measurement of the winding temperature at the hottest place in the transformers.

According to IEC 60076-7 [15], equations for the relative ageing rate calculation are based only on the hot-spot temperature as the controlling parameter is:

$$V = 2^{(\theta_h - 98)/6} \qquad (1)$$

where:

V – relative ageing rate

θ_h – hot-spot temperature in °C.

The loss of life L over a certain period of time is according to standards [2] and equation (2):

$$L = \int_{t1}^{t2} V dt \quad or \quad L = \sum_{n=1}^{N} V_n \cdot t_n \qquad (2)$$

where:

V_n – relative ageing during interval n

t_n – n^{th} time interval

n – number of each time interval

N – total number of intervals.

Example of values for hot-spot temperature is shown in figures Fig. 1 and Fig. 2. This data can be used for the owner to calculate the loss of life over certain period.

It is possible to calculate the relative ageing factor from the winding temperature for which we assumed it represents the hottest spot in the transformer winding.

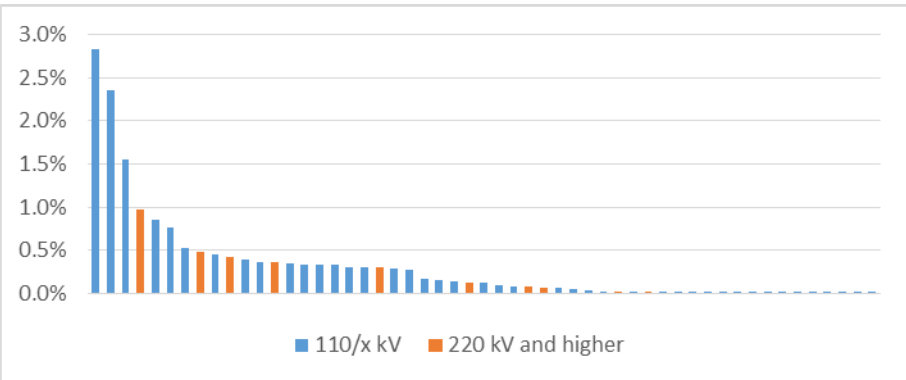

Fig. 7. Annualized relative ageing rate (calculated from winding temperatures of 52 transformer units)

Calculation showed that all transformers except one had annualized relative ageing rate below 3%. Small relative ageing rate indicates that the main factor for determining of lifetime of the paper isolation is minimally related to the temperature, and much more on natural aging process of cellulose, humidity, oxygen content and acid in the oil.

5. Conclusion

The paper gives an overview of the information already available and archived in modern SCADA systems for transmission systems, which can be used for centralized monitoring of the life of transformer and to help in scheduling regular, predictive and corrective types of maintenance. After analysis of the data, automated reports can be generated for different time periods (fro week, month, year or decade). Those data can be used for modifying of TSO maintenance and operation procedures which can include tuning of automatic voltage regulators. Centralized monitoring of transformers creates reports that are grouped by measurement type, transformer type and region (different parts of network or voltage levels). In these kinds of reports it is possible to compare data thus finding the anomalies in data or transformers. Reason for anomalies can be found in faulty sensors or in transformers.

Winding temperatures found in SCADA were used for calculating of the relative ageing rate of the transformers. Using active power measurement it was possible to calculate working hours of the transformers. Tap changer position movements (operations) showed that small number of transformers had many tap changer movements which would require increased maintenance of the tap changer devices.

This study indicates that special care should be taken for all kinds of transformer sensors, measurements and signals that are connected to SCADA system in control centers. This work shows the value in standardization of transformer data utilized for centralized monitoring purposes. Those data will be more intensively used for all kinds of transformer asset business procedures.

Future important work must be on analyzing of the signals and faults in the vicinity of the transformers that affect transformer lifetime, and adding statistics on transformer energization. For this work to be possible it is necessary to determine the periods when transformer is in operation. There is also no obstacle for collecting data from specialized transformer monitoring system directly into SCADA system.

This paper shows that with data already present in SCADA systems it is possible to monitor significant number of TSO transformers.

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