Contributions concerning the short-circuited mobile coil transformers

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Abstract: In this paper there are analyzed the two types of mobile coil transformers, the short-circuited mobile coil transformer and the transformer with axial moving coil. The voltage adjustment features are analyzed using the two devices. Also the author presents equivalent circuit and its implications regarding the functioning of the two types of transformers. There are examined the factors affecting the "0" voltage value and some solutions are proposed in order to reduce this value. A demonstration model is presented related to the solutions presented early in the paper.

Keywords: Mobile coil, residual voltage, transformer, voltage regulation, magnetic core.

1. Introduction

The technical progress and the developing of the modern power systems led to the increase of the number and of the value of electrical power requested by the consumers whose operations is influenced by the supply voltage. These influences consist in the need of voltage regulation between wide limits, with special requirements regarding refinement and precision regulation, but also to maintain constant voltage.

But there are some installations that require rigorously constant voltage supply, such as electronic computing equipment, industrial automation equipment, medical installations.

So the realization of devices for adjusting the voltage is an important task and at the same time complex because of implications of practical and theoretical.

2. The current technical stage regarding the movable winding transformers.

The short-circuited mobile coil transformers, together with the axial moving coil transformers are parts of the transformers with relative movement of windings category. Also this category includes three other devices:
- induction regulator;
- transformer with moving coils without intermediate windings;
- transformer with voltage regulation by changing the magnetic coupling between primary and secondary winding.

2.1 The transformer with axial moving coils

From the voltage regulating devices with relative movement of windings category belongs the axial moving coil transformer. [2] The magnetic system of this transformer is a three columns type, the mobile side part being the yoke, in whose cavities the primary winding is mounted, built from two sections connected in parallel.

In fig. 1 it is presented this type of axial moving coil transformer.

In this figure 1, and 1’, represents the primary winding sections connected in parallel. The central part, the column, it is immobile and in its cavity it’s placed the secondary winding. 2. The secondary voltage value, $U_{20}$, depends of the secondary winding position related to the primary winding’s sections whose inducing flows $\Phi_1$ and $\Phi_2$ are in opposition. So the secondary voltage value $U_{20}$ is proportional with the inducing flows difference, inducing flows which cross the secondary winding.
Next there are presented the principals positions of the axial moving coil and the way that influences the output voltage value:

As it can be easily observed the secondary voltage $U_{20}$ can take a maximum value, a medium value or it can take a zero value but it can also take an intermediate value depending on the moving coil position. The maximum value it is obtained when the moving coil is in one of the two extreme positions, when the inducing resulting flow is maximum (Fig. 2 a) and c) having one of the values, $\Phi_1$ or $\Phi'_1$. For the end positions, the secondary voltages that are measured are inversely.

For this type of transformer it is built a three-phase device used for power values up to 1600 kVA and a single phase variant called “Schubtransformator”, realized for values up to 840 kVA. [4]

2.2 The transformer with short-circuited mobile coil

Other solution that can be used for continuously voltage adjustment is the transformer with the secondary coil short-circuited and having the possibility to move over the primary winding. [1], [3]. These types of transformers were constructed by the power transformers factory (MEZ) from Moscow, for powers up to 200 kVA, [1]. The principle diagram of one of this kind of transformer is presented in figure 3:

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$U_{20} = 0.05 \cdot U_1$, value that grows to $U_{20} = 0.95 \cdot U_1$ when the mobile coil is at the other end of the column, overlapped with section $1'$. The middle position of the mobile coil determines a value of voltage equal to $U_{20} = 0.5 \cdot U_1$. The voltage variation in this case is obtained smoothly, continuously, without interrupting the load current and without using mobile contacts that are exposed to the scuff.

Having a wide variation range of the regulated voltage, this type of transformer is used in some testing installations for supplying the testing transformers, at the reduction unit verification stations and some preventive testing facilities for use in operating power plants and large stations. [1] For distribution networks is sufficient to use a range of 15 to 20% voltage variation.

This can be achieved with a variant of this type as shown in Fig. 5.

![Fig. 5. Mobile short-circuited coil connections diagram and the inverter for connecting the additional coil [6].](image)

The voltage obtained from this type of transformer can be varied in a wide range of values.

From the figure it is noted that if the auxiliary coil 4, connection is reversed then the regulated voltage collected from this section will be deducted from the output voltage and so the secondary voltage will be varied from 90 V to 100 V.

Properly choosing the number of turns of the additional section 4, it can be achieved necessary voltage adjustment. Such devices are used with regular power transformer and usually have a common oil tank.

The controller itself is actually composed of two immobile coil-type transformers, arranged on a coil core and a mobile short-circuited coil that can be moved by an actuator.

Use of these devices is limited due to a significant disadvantage, namely the emergence of large losses and significant current load.

### 3. The functioning of a short-circuited mobile coil transformer

The functioning of a short-circuited mobile coil transformer is similarly to one of a voltage divider.

![Fig. 6. Principle diagram of a voltage divider, [1].](image)

If the $R_f$ and $R_v$ resistances are replaced with two impedances $Z_f$ and $Z_v$, connected in adjustable assembly supplied in alternate current we obtain the same effect.

In order to easily understand this device way of function it's necessary to remember the equivalent principle diagram of a transformer, as it is showed next:

![Fig. 7. Transformer equivalent diagram , [1].](image)

Equivalent circuit components are:

- $Z_m$ - magnetizing circuit impedance;
- $R_1$ - ohmic resistance of primary winding;
- $X_{o1}$ - leakage reactance of primary winding;
$R_2$ - ohmic resistance of the secondary winding relative to the primary;
$X_{o2}$ - leakage reactance of the secondary winding relative to the primary;
$Z'_c$ - load impedance reported to the primary winding;
$I_0'$ - equivalent load current;
$I_2''$ - secondary winding current;
$I_1$ - primary winding current;
$U_1$ - supply voltage of the primary winding;
$U'_2$ - secondary load voltage.

Were $Z'_1 = 1 + \frac{Z_{c1}}{Z_m}$ is a correction factor.

In case that $Z'_c = \infty$ then the operating regime of the transformer is no-load, as it is shown in the figure below:

![Fig.8](image)

**Fig.8.** Equivalent diagram of a transformer running with no load, [1].

In case that $Z'_c = 0$ the transformer is working at short-circuit regime and the principle diagram is shown next.

![Fig.9](image)

**Fig.9.** Equivalent diagram of a transformer working at short-circuit regime, [3].

If $I_0' \ll I_2''$ then we will consider $I_{1k} \approx I_{2k}$ in which case fig. 9 will be reduced to fig.10 presented next:

![Fig.10](image)

**Fig.10.** Short-circuited working regime principle diagram, [1].

### 4. Experimental data

In the image below it is presented the device built in the laboratory. The stand includes both a short-circuited mobile coil transformer and a transformer with axial moving coil.

![Fig.11](image)

**Fig. 11.** The two types of transformers, [1].

The experimental device is composed from a single phase magnetic core having two columns. On one of the columns is placed the primary winding divided into two identically, immobile sections, connected in series and placed at the endings of that column.

Concentric with these two sections a secondary winding connected in short-circuit is moving.

The adjusted voltage is collected from the terminals of one of the sections of the primary winding.

Each of the two sections of the primary winding has a number of 668 turns realized from copper wire insulated with PTA email and having the diameter of 0.8 mm.

During the testing actions over this device a series of values of the adjusted voltage was obtained, for a supply voltage range between 100 - 210 V, values presented in the next tables.
The described device principle diagram is presented below:

![Diagram of a short-circuited mobile coil transformer.](image)

**Fig. 12.** Short-circuited mobile coil transformer, [1].

Initial we used a mobile short-circuited coil having 242 turns, made from the same wire type as the primary winding. This winding is considered to be the secondary winding for this transformer.

**TABLE 1.** Adjusted voltage values for a secondary winding with 242 turns.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>100</td>
<td>10.77</td>
<td>43.9</td>
<td>91.45</td>
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<td>160,4</td>
<td>20.56</td>
<td>77.56</td>
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<tr>
<td>170,2</td>
<td>22.97</td>
<td>85.71</td>
<td>151.9</td>
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<td>26.45</td>
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<tr>
<td>190</td>
<td>30.5</td>
<td>90.86</td>
<td>167.5</td>
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<tr>
<td>200,7</td>
<td>34.8</td>
<td>94.04</td>
<td>174.2</td>
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<tr>
<td>210,7</td>
<td>40.3</td>
<td>98.36</td>
<td>181.1</td>
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</table>

Unfortunately, as it can easily be observed the adjusted voltage minimal value, value that is obtained for the upper extreme position of the mobile coil isn’t fit for the prescript value of 5%.

[6]

We try to reduce the amount of residual voltage corresponding to the “0” position of the short-circuited mobile coil.

Because it was impossible to modify the magnetic core geometry or the column length we considered on changing the number of turns for the mobile winding. We decided to decrease the number of turns by 25%.

**TABLE 2.** Adjusted voltage values for a secondary winding with 182 turns.

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<tbody>
<tr>
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<tr>
<td>143</td>
<td>18.74</td>
<td>63.44</td>
<td>126.1</td>
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<td>20.21</td>
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<td>163,6</td>
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<td>26.5</td>
<td>75.24</td>
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<td>191,9</td>
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<tr>
<td>201,2</td>
<td>44.4</td>
<td>92.09</td>
<td>168.1</td>
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**TABLE 3.** Adjusted voltage values for a secondary winding with 62 turns.

<table>
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<tr>
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<td>12.86</td>
<td>51.4</td>
<td>99.43</td>
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<tr>
<td>122,8</td>
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<td>108.5</td>
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<tr>
<td>201,2</td>
<td>44.4</td>
<td>92.09</td>
<td>168.1</td>
</tr>
</tbody>
</table>

The data we collected weren’t good enough; the adjusted voltage value didn’t change much. We decided to connect another supplementary winding in series with one of the primary sections.

We constructed a winding having 208 turns made from the same material as the primary sections and we placed it on the free column connected in series with the section at whose terminal we collect the regulated voltage.

We supplied the primary winding with a voltage value equal to 100 V and we obtained for the “0” position of the mobile coil, an adjusted voltage of 5.4 V.

It can be observed that this value is very close to the one prescript in the current stage.
4. Conclusions

A transformer functioning with no load is equivalent with high value impedance connected at the power supply.

A transformer with the secondary winding connected in short-circuit is tantamount with low value impedance, connected at the power supply.

Therefore, the short-circuited mobile coil device, used to continuously adjust the voltage, can be understood as a result of using the two equivalent single phase transformers, α and β, with primary windings in series, all of which are connected to the power supply. Each of these two equivalent transformers is built with a primary winding, with the number of turns equal to a section of the real transformer winding.

References:


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