PHASE-SHIFT TRANSFORMER WITH IMPROVED CHARACTERISTICS

Mihai TIRSU, PhD[1], **Vladimir BERZAN,** dr.[1], **Lev CALININ,** PhD[1], **Dmitrii ZAITEV** PhD[1]

[1]Institute of Power Engineering of Academy of Sciences of Moldova, Chisinau, Republic of Moldova

REZUMAT. Transformatoarele de reglare a decalajului de fază (TRDF) sunt componente cruciale în lupta ce se desfăşoară pentru îmbunătățirea eficienței rețelei de curent alternativ şi eliminării congestiilor. Creşterea permanentă a energiei electrice transportate aduce liniile la valoarea lor de limită, majorând riscul stabilității rețelei. TRDF sunt mijloace cost-eficiente pentru a soluționa controlul sigur şi eficient al fluxului de putere în liniile electrice de transport supraîncărcate. În această lucrare se prezintă o soluție tehnică inovativă de realizare a instalației de reglare a decalajului de fază

Cuvinte cheie: PST, transformator de reglare a decalajului de fază, FACTS controler.

ABSTRACT. Phase shifting transformers (PST) are crucial components in the ongoing strive for improved AC network efficiency and congestion elimination. Increasing amounts of transmitted energy push the networks to the limit, increasing the risk of network instability. PSTs are a cost-effective means to ensure reliable and efficient power flow control in overloaded transmission lines. In this paper, is presented a new PST design which is more cost-efficient technical solution.

Keywords: PST, phase shift transformer, FACTS controllers

1. INTRODUCTION

Improved system operating performance and efficiency PSTs allow to control the power flow in the transmission grid independently of the generation [1]. Total power flow is influenced by modifying the load share of parallel lines. System reliability is improved by mitigation of post-contingency overloads and of unwanted power transfer. By balancing the power flow in the network and optimizing the electrical power flow, grid owners can minimize the electrical losses in their system.

On the other hand, tend to increase the share of renewable sources in the energy balance involves the need to use specialized equipment to solve problems of bottlenecks and distribution. Equipment such as can serve phase-shift transformers and other equipment in this class.

However, these are enormously expensive. Therefore, this issue is dedicated to a large number of scientific articles, authored with scientists from around the world. In addition to the power unit has particular importance and power electronics used to change the phase shift.

The phase shift installations, as rule, are realized on base of technical solution called "Marcereau Connection" [2],[3],[4]. Installation based on this technical solution has rated power of 2.15 higher than transmitted.

This paper proposed an innovative technical solution of PST realization, which allows reducing rated power of installation up to 1.61 compare to transmitted power, what is about 33% less than traditional technical solution. At the same time, is proposed also an innovative technical solution for power key system what connect in steps selected phase shift

2. DELTA/HEXAGON SCHEME OF PST

Institute of Power Engineering of Academy of Sciences of Moldova has a large experience in the field of elaboration of power flow control equipment in electrical transport lines. Among these is the phase shift transformer (PST). As rule, PST consists of two transformers: exciting transformer and boosting transformer.

Technical solution proposed in this paper also consists from two transformers (so called two-core installation). General scheme is presented on fig.1.

From fig.1 it can be seen what the proposed technical solution is kind of hexagon (delta scheme). This kind of solution is also well used in practice [5]. Excitation transformer is marked with index q, and the boosting transformer is marked with index p. Excitation transformer consists from 4 windings. Primary winding is marked with index W_{1q} and is consecutive connected with winding of another transformer marked with W_{3q}. Relation between these windings is selected such to provide a phase shift of 30 degrees than voltage on winding W_{2p} is missing. The secondary winding is marked with W_{2q} and is divided in two equal windings – $W_{2q}^{'}$ and $W_{2q}^{"}$. The winding constitute 5/7 of total voltage and $W_{2q}^{'}$ constitute only 2/7. At the same time, the winding $W_{2q}^{'}$ is provided with intermediary output what separate voltage of this winding in two equally parts.

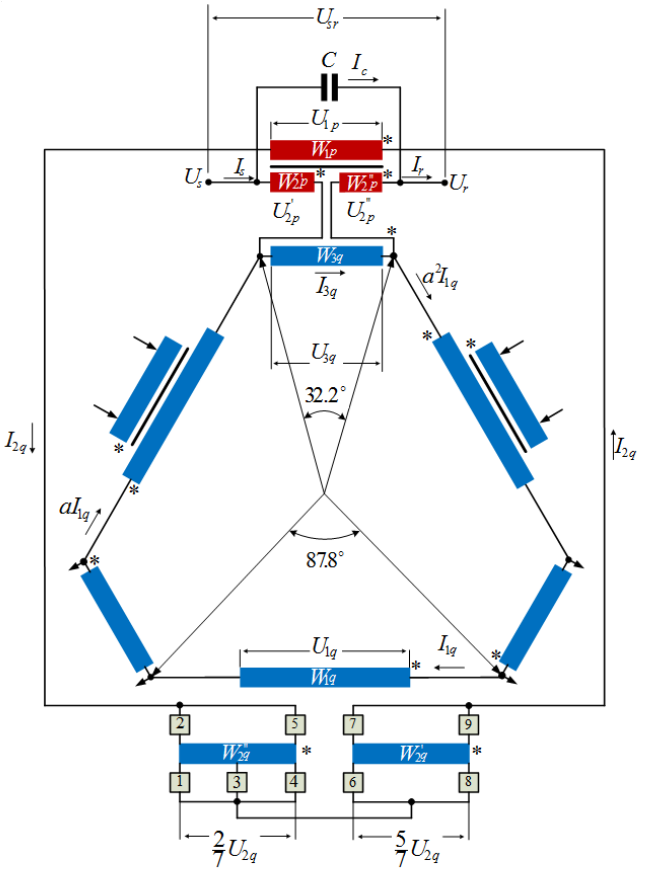


Fig.1. General scheme of technical solution of PST realization

Boosting transformer is composed from two windings: primary winding marked as W_{1p} and secondary winding, which is formed from two equally windings marked respectively as $W_{2p}^{'}$ and $W_{2p}^{"}$. The summary voltage of these two windings is equally to voltage of winding W_{3q}.

Input voltage is applied at taps marked as U_S and the output voltage is taken across taps marked U_r.

Generally, they can be changed with the place, but in this case phase shift will have negative values.

3. COMPUTATION OF INSTALLATION TRANSFORMERS PARAMETERS

In order to get practical approval of proposed technical solution was manufactured a sample of PST with rated power of 10kW and input voltage 380V. For computation of installation characteristics (transformers parameters) were established maximal parameters of all windings. Maximal load current is 12A. Obtained results are presented in table 1.

Table 1

Maximal windings parameters of excitation and boosting transformers for proposed solution presented on fig.1.

W	W_{1q}	$W_{2q}^{'}$	$W_{2q}^{"}$	W_{3q}	W_{1p}	W_{2p}
U_{max}, V	332	189,5	76	132,8	265,8	135,4
I_{max}, A	7.2	5,9	5,9	12	5,9	12

Using parameters presented in table 1 we can calculate the rated power of each winding, and as result the installation rated power.

Rated power of boosting transformer separated on windings:

$S_{W_{1p}} = 265.8 \cdot 5.9 = 1568.22W$ - rated power of primary winding of boosting transformer;

$S_{W_{2p}^{'}} = 135.4 \cdot 12 = 1624.8W$ - rated power of secondary windings of boosting transformer;

$S_p = \frac{S_{W_{1p}} + S_{W_{2p}}}{2} = 1596.51W$ - rated power of boosting transformer;

$S_{W_{1q}} = 332 \cdot 7.2 = 2390.4W$ - rated power of primary winding of excitation transformer;

$S_{W_{2q}^{"}} = 76 \cdot 5.9 = 448.4W$, $S_{W_{2q}^{'}} = 189.5 \cdot 5.9 = 1118.05W$,

$S_{W_{3q}} = 132.8 \cdot 12 = 1593.6W$ - rated power of secondary windings of excitation transformer.

$S_q = \frac{S_{W_{1q}} + S_{W_{2q}^{'}} + S_{W_{2q}^{"}} + S_{W_{3q}}}{2} = 2775.2W$ - rated power of excitation transformer.

$S_{PST} = S_p + S_q = 4371.7W$ - rated power of installation;

$S_r = U_r \cdot I_r = 226.5 \cdot 12 = 2718W$ - transmitted power by installation;

$\frac{S_{PST}}{S_r} = 1.61$ - relation between rated power of installation and transmitted power.

The last relation is very important because show the performance of proposed technical solution in comparison with traditional solution maintained the same parameters. This index can be improved if we will use a capacitor connected in parallel with input and output of installation how it is shown in fig.1. In our case was selected a capacitor of 90 mkF. In this case we reduced this index up to 0.93. But for each case separately may be selected a capacitor depends of rated power of installation and maximal phase shift and obtains a cost-efficient solution.

4. POWER ELECTRONIC MODULE

As rule, necessary phase shift selection is done by help of mechanical tap. But, in modern conditions, then level of network integration is constantly growing it is request a more and more flexibility. This means a more quickly reaction (answer) of these installations to network fluctuations. For this reason, more frequently the mechanical switchers are replaced by power electronic keys. Depending on applied switching scheme and realization scheme of installation the number of key are different. The price of power electronic keys is also different in function of voltage level on which they work.

The technical solution proposed for realization of electronic commutation circuit allows reducing the cost with about 20% and additional reduces the level working voltage. The developed scheme is presented on fig.2.

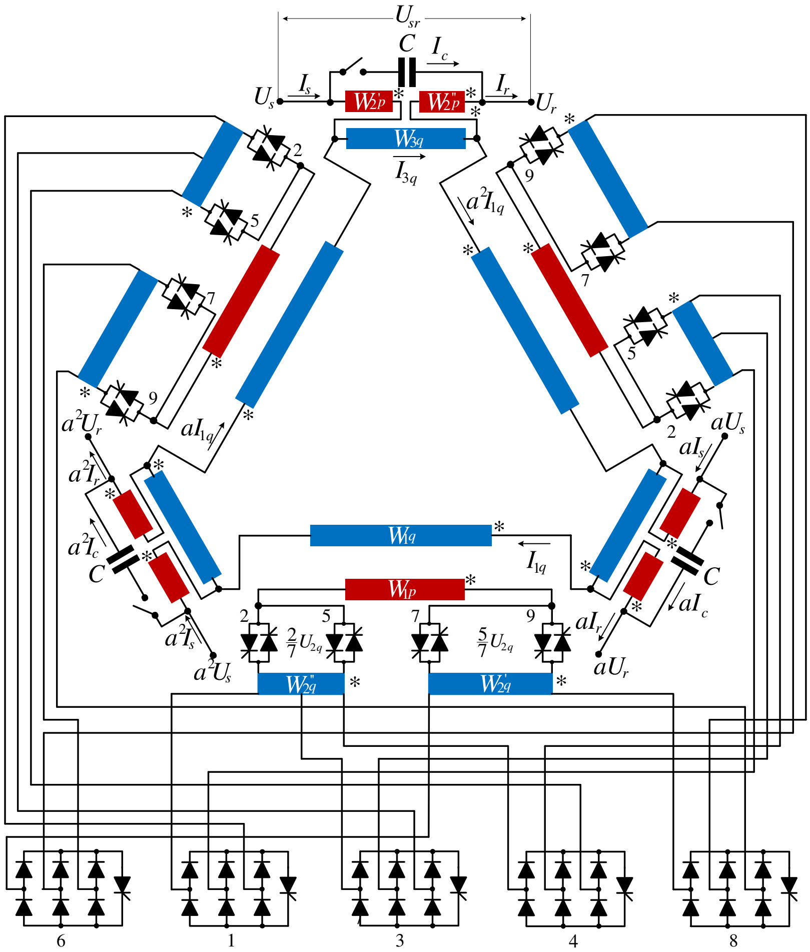


Fig.2. General scheme of power electronic module

On fig.2 is shown the extended scheme of electronic keys module which provide commutation of needed phase shift. The advantage of electronic module consists in using of diodes instead of controlled keys, what allow reducing the cost of whole power electronic module. On the other hand, this allows simplifying the control algorithm of power electronic module.

For this scheme was developed control algorithm of phase shift in steps, each step has a value of 4,2 degree (fig.3).

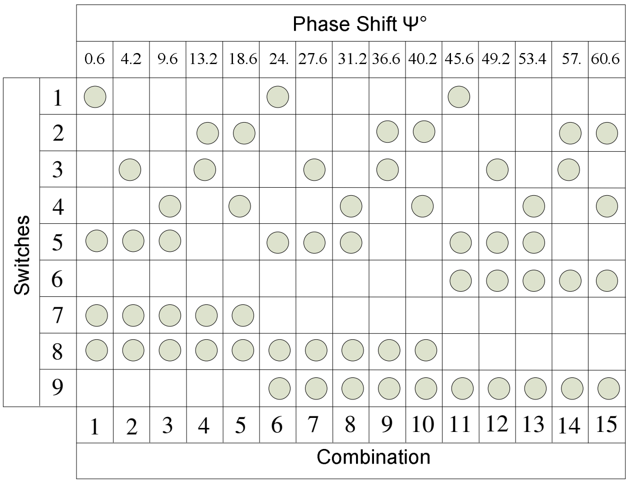
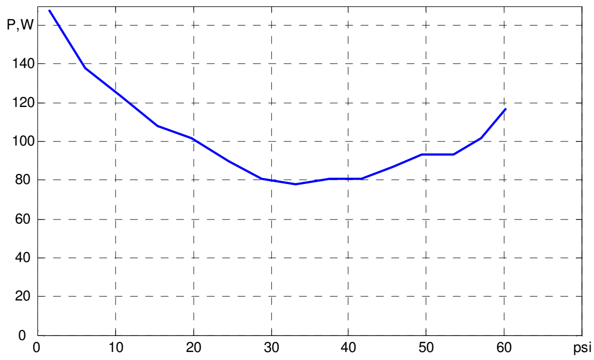


Fig.3. Work diagram of power electronic module

From fig.3 it can be seen, what for any position there is connected four keys. Number of steps is 14. Step consists 4,2 degree and this value is selected in order to not exceed the allowed value of harmonics (3%) in electrical energy transport lines.

5. TEST OF PST POWER MODULE

In order to verify correctness of proposed technical solution was manufactured a sample of 10kW for which were done verification tests. During tests the power key were replaced by mechanical switchers. The installation was verified for both idle mode and short-circuit mode. Obtained characteristics a presented on fig. 4.



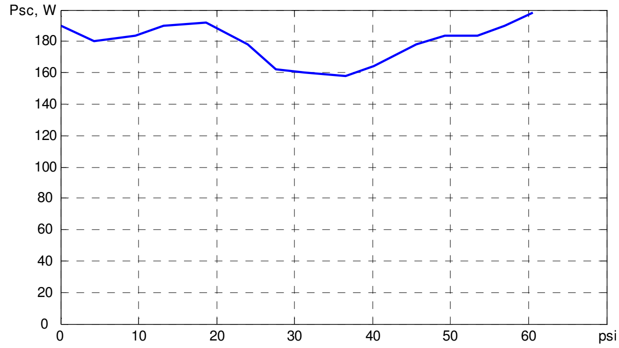
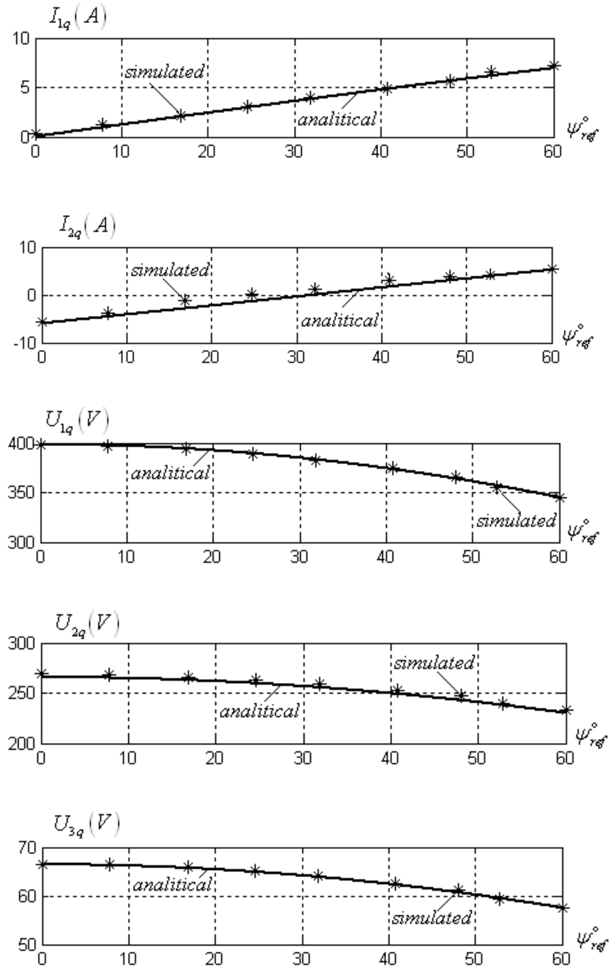


Fig.4. Losses in installation for idle (first) and short-circuit modes (second) in function of phase shift

From this figure it can be seen that losses in installation for both modes not exceed value of 2,7% which is very well. For short-circuit the current mode was maintained at constant value of 12A.

For additional verification was developed both mathematical and simulink (MATLAB) models of installation. Result comparisons are presented on fig.5.



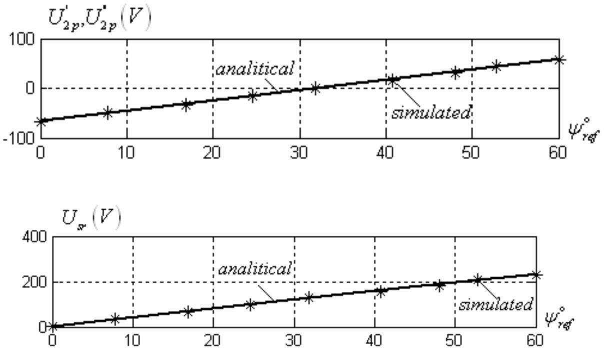


Fig.5. The analytical and simulated result comparison for proposed solution

6. CONCLUSIONS

✓ In paper was proposed an innovative technical solution of two core PST realization, which allowing decrease the rated power with about 33% in comparison with classical solution "Marcereau Connection".

✓ The power electronic module of phase shift switching which has a reduced rated power with about 20% in comparison with existing practically solutions was developed.

✓ The control algorithm of power keys which provide change of phase shift in range of 0-60 degrees by step of 4,2 degree was developed.

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About the authors

Calinin Lev Pavel email: kalinin_lev@ie.asm.md
31.07.1934. He graduated from the Odessa Polytechnic Institute (Ukraine) in1963. In 1982 he defended his thesis for the degree of candidate of technical sciences in the NETI Novosibirsk (Russia). Research of interests related to the application of FACTS controllers in power systems.

Zaitev Dmitrii Alexandru email: zaiats@ie.asm.md
10.04.1963. He graduated from the Polytechnic Institute of Chisinau (Moldova) in1985, defended his thesis for the degree of candidate of technical sciences in 2000 at the Institute of Energy Sciences of the RM. His research interests lie in the field of study modes of power systems containing flexible interconnections. He is the head of "Electro-technical equipment and power electronics" Laboratory.

Tirsu Mihai Stefan email: tirsu.mihai@gmail.com
27.02.1972. He graduated from the Technical University of Moldova in 1994, specialty "Automation and control of technical systems". In 2003 he defended his thesis for the degree of candidate of technical sciences. He is deputy director of the Institute of Power Engineering of the Academy of Sciences of Moldova. Basic research in the field of transport networks control, diagnostics of high-voltage equipment, power electronics, etc.

Berzan Vladimir Petru email: berzan@ie.asm.md
28.01.1948. He graduated from the Technical University of Moldova in 1971, specialty "Electrical machines and apparatus systems", activity at the Institute of Energy of ASM as an engineer, scientist, Head of Laboratory, Deputy Director for Science, Director . PhD thesis was supported in 1991 the State Technical Universityof Saint Petersburg (Russia), thesis Ph.D of science in 1999 at the Institute of Energy of the ASM. Publications: all-over 215, including patents monographs -12 and - 15.