POWER ELECTRONIC SYSTEM BASED ON IGBT TRANSISTORS FOR PHASE SHIFT INSTALLATION

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Abstract. *In paper the innovational technical solution of phase shift installation, which allowing decrease the rated power of installation up to 20% without using of condenser keeping the same performances of installation and up to 50% using the capacitor bank connected in parallel of installation, is described. The scheme of electronic power system used for switching of phase shift is elaborated and shown here as well. Phase shift change is made in steps, and totally we have 14 steps of 4.2 degree each of them. Electronic power system is made on base of IGBT transistors and allowing decreasing of rated power of power keys up to 34% in comparison with analog.*
Keywords: *PST, power electronic, phase shift*

SISTEM ELECTRONIC DE PUTERE BAZAT PE TRANZISTORI IGBT PENTRU DIRIJAREA CU UNGHIUL INSTALAŢIEI DE REGLARE A DECALAJULUI DE FAZĂ

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Rezumat. *În lucrare se prezintă o soluţie tehnică inovativă de realizare a instalaţiei de reglare a decalajului de fază, ce permite reducerea puterii instalate cu până la 20% fără utilizarea băncii de condensatoare în paralel şi cu până la 50% dacă se utilizează banca de condensatoare. Se prezintă de asemenea şi sistemul electronic elaborat utilizat pentru comutarea decalajului de fază necesar. Decalajul de fază se modifică în trepte cu pasul de 4.2 grade. În total sunt 14 trepte, ce dă posibilitate de reglare a decalajului de fază în diapazonul 0-60 grade. Sistemul electronic este realizat în baza tranzistorilor IGBT şi permite reducerea puterii instalate cu până la 34% în comparaţie cu sistemul analog.*
Cuvinte cheie: *transformator de reglare a decalajului de fază, sistem electronic de comutare a unghiului*

СИЛОВОЙ ЭЛЕКТРОННЫЙ КОММУТАТОР, ОСНОВАННЫЙ НА IGBT ТРАНЗИСТОРОВ ДЛЯ УПРАВЛЕНИЯ УГЛОМ УСТАНОВКИ ФАЗОВОГО СДВИГА

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Реферат. *В статье представлено новое инновационное техническое решение реализации фазоповоротного устройства, которое позволяет снизить на 20% установленную мощность, если не использовать конденсатор параллельно и на почти 50%, если включить банку конденсаторов. Также представлена силовая электронная система для коммутации необходимого угла фазового сдвига. Угол меняется ступенчато с шагом 4.2 градуса, всего 14 ступеней, которые позволяют менять угол в диапазоне 0-60 градусов. Предложенная система имеет установленную мощность на 34% меньше по сравнению с аналогом.*
Ключевые слова: *ФРТ, фазовый сдвиг, электронная система переключения угла*

INTRODUCTION

Constantly increasing world electrical energy demand conduct to necessity of finding new technical solutions in order to overcome electrical energy deficit. On the one hand appear new technologies electrical energy of which are less, and on the other hand people trying to find new more rational paths of electrical energy supplying. Among these measures is the power systems interconnection and realization of so called "smart grids". But, taking in consideration that these systems having different parameters, it is not enough to done a simple connection. For this purpose it is necessary to have a special devices by means of which we can control with power flows and providing a request protection. As result of solving these problems it was developed a whole class of such devices, called FACTS (Flexible Alternative Current Transmission Systems) controllers. Among these devices an important place has Phase Shift Transformers (PST), which destination is to modify phase shift between input and output voltages of installation in nodes of transport network for management with power flows. It is worth to mention that these devices are quite expenses. From this reason a lot of researches are directed to solving this problem – reducing the cost of these [1,2,3]. As rule, such kind of devices consist of 2 transformers (2 core design) – excitation transformer and serial transformer, including the system of phase shift commutation.

The more used technical solution of PST is so called "Marcereau Connection" [4]. The advantage of this solution is: keep practically constant output voltage in all rage of phase shift modification. Currently researches are being conducted in two directions:

1. Decreasing of mass and dimensions of installation keeping the same capacity, taking in consideration their expensiveness.

2. Reducing time of phase shift changing and increasing the degree of power system management

The standard technical solution ("Marcereau Connection") need to have rated power of installation twice bigger then transmitted power. In such kind of installations usually it is used mechanical switching system to change phase shift. In order to fast process of phase shift change in [5] it is proposed an electronically system of commutation based on thiristors. The process of thiristors management is quite difficult, because their does not close after removing control signal. As result, the thiristors are closed only if current stop run in their circuit.

In paper it is shown a new innovative technical solution of PST realization, which allowing decrease the rated power almost twice, and two variants of electronically switching system based on IGBT transistors.

1. TECHNICAL SOLUTION OF IMPROVED PST

The proposed technical solution is based on standard solution "Marcereau connection" and is a 2 core design as well. This technical solution gives us opportunity to increase load in autotransformer mode and decreasing rated power of serial transformer (boosting transformer). The proposed technical solution of PST realization is shown on fig.1.

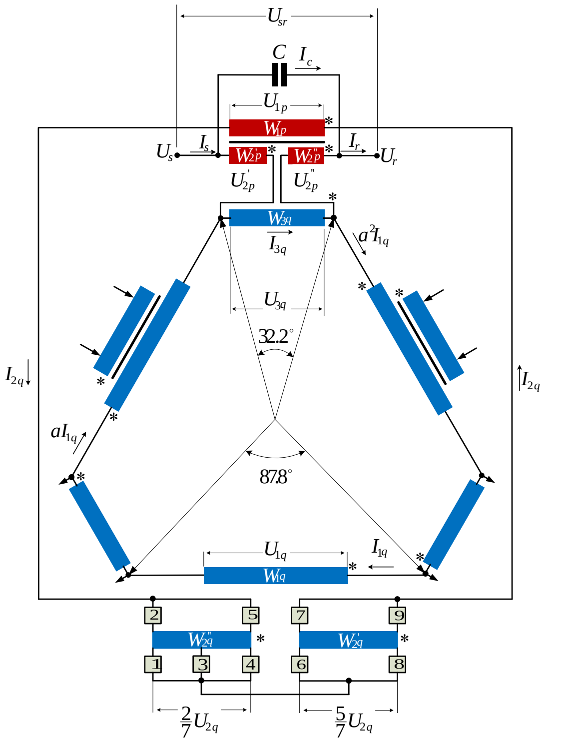

Figure1. Technical solution of improved PST

The installation presented on Fig.1 consists from 2 transformers: excitation transformer marked by index *q* and boosting transformer marked by index *p*. Input voltage is noted by U_s and output voltage by U_r. The excitation transformer consists of 4 windings. Primary winding is marked as W_{1q} and is series connected with W_{3q} winding. The relation between these windings is selected so to ensure phase shift of 30 degrees then voltage on winding W_{2p} is missing. Secondary winding of excitation transformer is marked as W_{2q} an is divided in two parts – $W_{2q}^{'}$ and $W_{2q}^{''}$. The winding $W_{2q}^{''}$ contains 5/7 of voltage U_{2q} and winding $W_{2q}^{'}$ has $2/7U_{2q}$. At the same time $W_{2q}^{'}$ is provided with tap on middle point and separate voltage of this winding in two equal parts. The boosting transformer is formed by two windings – primary winding noted as W_{1p} and secondary winding consists from two separate windings $W_{2p}^{'}$ and $W_{2p}^{''}$. Summary voltage of these windings is equal to voltage of winding W_{3q}.

In order to approve proposed technical solution it was elaborated sample of power 10kVA. In [6] it was proved that rated power of proposed technical solution in comparison with standard technical solution without using capacitor bank is about 1.61 of transmitted power. For standard technical solution (Marcereau Connection) this index is 2.0. This means that proposed technical solution allowing decreasing in rated power with about 20%. If for this sample the capacitor bank of 90mkF in parallel to installation is used we gain about 50% in rated power of transformers keeping the same performances of installation.

2. ELECTRONICALLY SWITCHING SYSTEM OF PST

First of all it should be noted that for system of this voltage class total harmonic distortions (THD) of output voltage should not exceed 3%. Following this we selected step of phase shift equal to 4.2 degrees and 14 steps of commutation to ensure range of 0-60 degrees. To be able perform algorithm of commutation we divided winding W_{2q} on two equal parts – first winding $W_{2q}^{'}$ has 2/7 of total voltage and second winding $W_{2q}^{''}$ has 5/7 of total voltage. At the same time the winding $W_{2q}^{'}$ has a tap from middle point (1/7). In general, how it is shown on fig.1 is necessary to apply 9 power keys on each phase, i.e. 27 keys for all system. This quantity of key is not possible to reduce if using mechanical switching system. In mentioned case each power key consists from two controlled keys. So, for whole system we need to use 54 fully controlled keys from which 24 works on voltage $5/7U_{2q}$, and 30 on voltage $2/7U_{2q}$. In order to have possibility to compare different commutation systems we will express the cost of power keys in relative units. So, we have 24 keys with cost of 1u.r., and 30 keys with cost at least 0.5u.r. (the voltage level of this keys is about three times less. If we will check the price of different producers will find that the price differs at least twice. So, we considered here a twice difference.). Taking in consideration about mentioned we have a relative cost of 39u.r. for this electronically system.

In this paper we proposed two variants of electronic power switchers which allowing decreasing number of power keys and as result their cost. First variant is shown on fig.2.

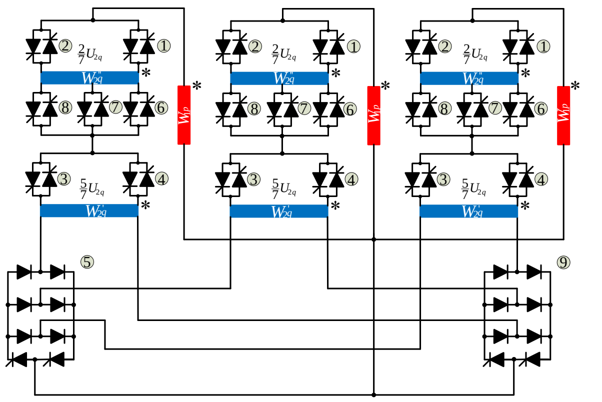

Figure 2. The scheme of electronic switcher which including 50 controlled keys and 12 diodes.

In this case we are using 12 keys on voltage $5/7U_{2q}$, 30 keys on voltage $2/7U_{2q}$, 4 keys on voltage $0.5U_{2q}$ and 12 diodes. If express in relative units we obtain:

12+0.5x30+0.7x4+0.25x12=12+15+2.8+2.5=32.3 u.r.

Obliviously, what for proposed system we gain about 17% in cost of power keys. On fig.3 it is presented developed algorithm for power keys to ensure phase shift change in all range of work.

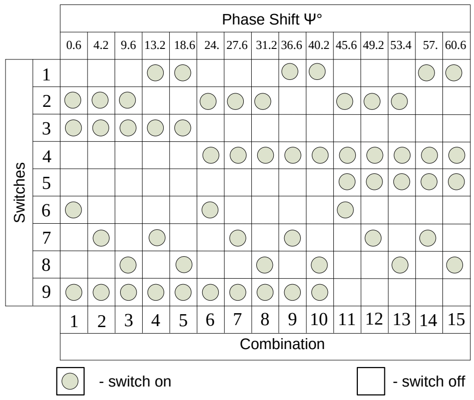

Figure .3. The switching algorithm of phase shift for scheme presented on fig.2

The simulink model was elaborated for scheme shown on fig.2 in order to proving correctness of this electronic switcher. The simulink model is shown on fig.4.

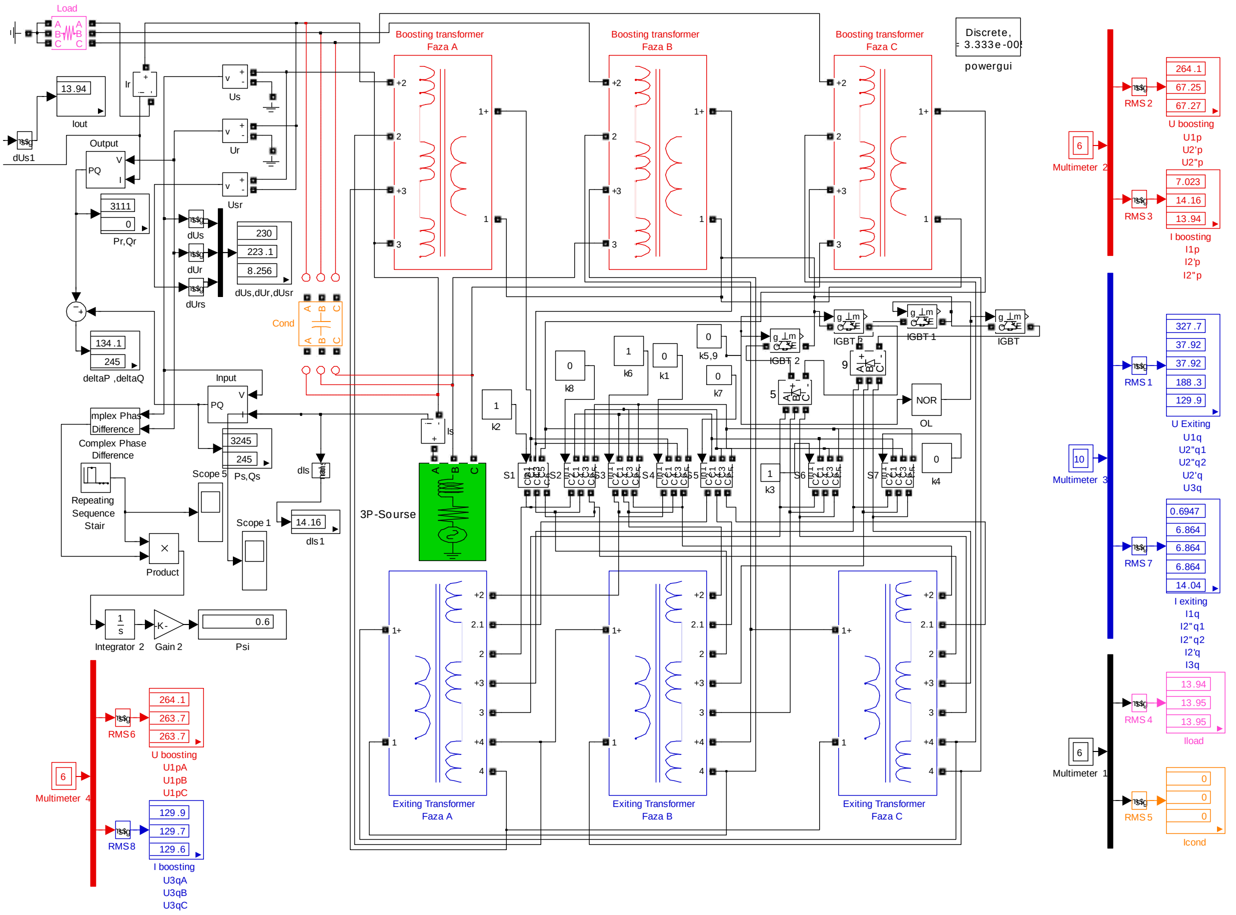

Figure 4. The simulink model for scheme presented on fig.2.

All parameters of simulink model are corresponding to that of sample of 10kVA. This model was used to obtain parameters of installation in idle mode and full load as well. As load it was selected an active resistance of 16 Ohm. For this case load current was near 14A. Obtained results are shown in tables 1 and 2.

Table 1.

Test results of installation for idle mode

Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ψ_s, ^{0}	0.6	4.2	9.6	13.2	18.6	24	27.6	31.2	36.6	40.2	45.6	49.2	53.4	57	60.6
Ψ_r, ^{0}	0.6	5.4	10.2	14.4	19.2	24	28.2	32.4	37.2	41.4	45	49.2	52.8	57	60.6
I_{in}, A	0.61	0.51	0.42	0.35	0.3	0.27	0.25	0.24	0.24	0.24	0.27	0.3	0.34	0.39	0.45
U_{in}, V	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230
I_{out}, A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U_{out}, V	229.6	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.7	229.	229.7
U_{sr}, V	1.14	19.9	38.8	57.5	76	93.7	111	128.3	145	161	176	190	204	217	229.8

Table 2.

Test results of installation for full load, R=16Ohm.

Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ψ_s, ^{0}	0.6	4.2	9.6	13.2	18.6	24	27.6	31.2	36.6	40.2	45.6	49.2	53.4	57	60.6
Ψ_r, ^{0}	0.6	4.2	9	13.2	18	22.8	27	31.8	36	40.2	43.8	48	51.6	55.2	58.8
I_{in}, A	14.14	14.14	14.11	14.04	14.01	14.05	14.1	14.15	14.14	14.14	14.12	14.18	14.23	14.23	14.23
U_{in}, V	230	230	230	230	230	230	230	230	230	230	230	230	230	230	230
I_{out}, A	14	14	14	14.01	13.98	14.03	14.06	14.1	14.07	14.04	14	14.04	14.07	14.04	14.02
U_{out}, V	223.3	224	225	224	224	224	225	226	225	225	224	225	225	225	224
U_{sr}, V	8	15.7	33.8	52	70	88	106	123	139	154	168	183	197	209	222
P, W	3247	3239	3232	3217	3209	3220	3232	3245	3245	3245	3244	3257	3270	3269	3268
Q, VA	246	233	222	217	214	204	197	187	174	160	153	141	135	143	153
ΔP,W	131	104	78	77	83	73	67	64	78	91	106	104	103	113	124
ΔQ,VA	246	233	222	217	214	204	197	187	174	160	153	153	135	143	153

In tables 1 and 2 we have the following notations: Ψ_s, ^{0} – given phase shift; Ψ_r, ^{0} – real obtained phase shift; I_{in}, A - input current of installation; U_{in}, V – voltage on entrance of installation; I_{out}, A – load current; U_{out}, V – output voltage of installation; U_{sr}, V – voltage between input and output of installation, which corresponds to selected phase shift; P, W – active power consumed by installation; Q, VA – reactive power consumed by installation; ΔP,W – active power losses in installation; ΔQ,VA – reactive losses in installation.

On fig.5 it is shown characteristics comparison between given phase shift and obtained real phase shift for both modes of installation idle and full load.

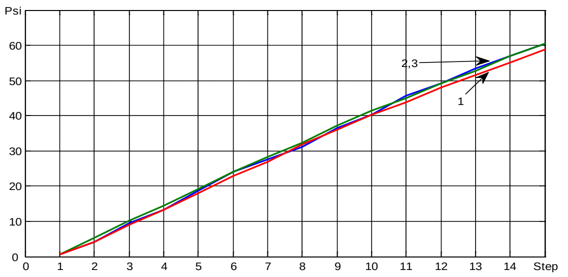

Figure 5. Comparison of set phase shift (2) with obtained phase shift for both modes idle (3) and (1) full load.

It can be seen that angle mismatch error does not exceed 2%, and the bigger error is obtained for maximal load. From table 2, also it can be observed that output voltage for full load does not differ from input voltage more than 3% in whole range of phase regulation.

On fig.6 the other electronically switching system which has improved characteristics in comparison with preview one is submitted.

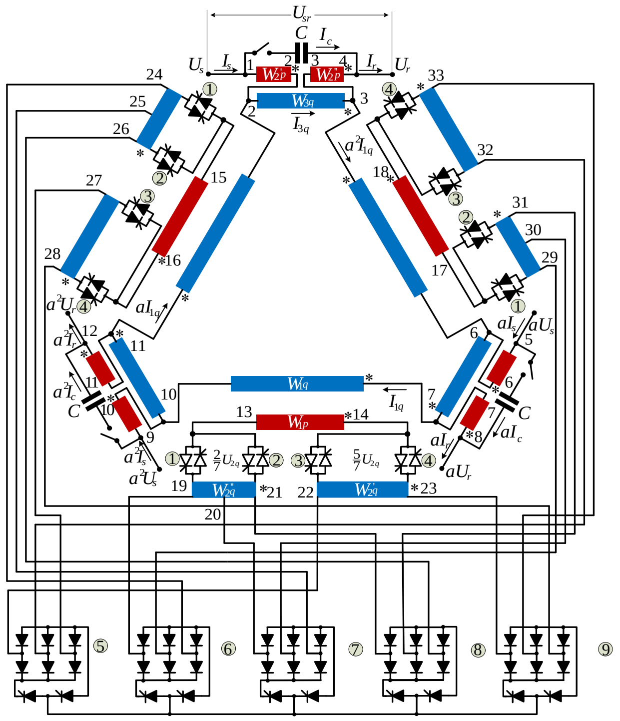

Figure 6. The scheme of electronic switcher with improved characteristics for changing of phase shift

Doing in this way electronic switcher we using only 32 controlled keys. From them 12 are working on voltage $5/7U_{2q}$, 12 on voltage $2/7U_{2q}$ and 10 on voltage $0.5U_{2q}$. In this case full relative cost of power electronic keys is:

$$12+0.5x12+0.25x30=12+6+7.5=25.5 \text{ u.r.}$$

So, the relative cost of this power key system is less with about 34% in comparison with standard electronic switcher.

For proposed electronic power key system it was developed a new switching algorithm of phase shift which is shown on fig.7.

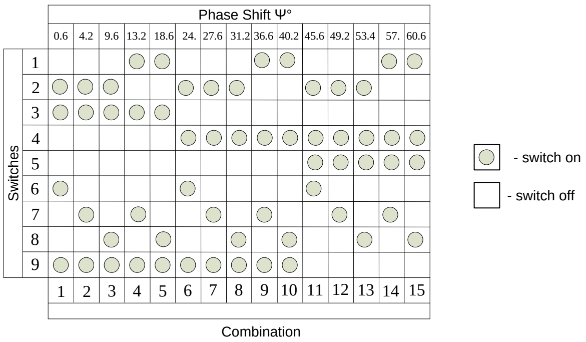

Figure 7. The algorithm of phase shift switching for scheme presented on fig.6.

From fig.7 it is obviously that this algorithm does not differ very much from preview one. The simulink model was updated for new scheme and respective tests were done. The results had shown that for all three cases THD of output signal does not exceed 0.4%. Results are shown in table 3.

Table 3

Total harmonic distortion of output current at using mechanical switcher, electronic switcher with 12 diodes and electronic switcher with 30 diodes at full load.

Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ψ_s, ^{0}	0.6	4.2	9.6	13.2	18.6	24	27.6	31.2	36.6	40.2	45.6	49.2	53.4	57	60.6
THD,% (I)	0.22	0.26	0.29	0.34	0.37	0.38	0.39	0.39	0.37	0.34	0.29	0.23	0.17	0.16	0.16
THD,% (I)	0.22	0.25	0.29	0.33	0.37	0.38	0.39	0.39	0.37	0.34	0.29	0.22	0.17	0.16	0.16
THD,% (I)	0.23	0.26	0.3	0.35	0.37	0.38	0.39	0.39	0.37	0.34	0.29	0.23	0.18	0.17	0.17

The small values of THD are due to using transistors as power keys which has small forward voltage. Additionally, at switching between different phase shifts then voltage curve cross zero does not appear overvoltage and missing voltage drop (fig.8).

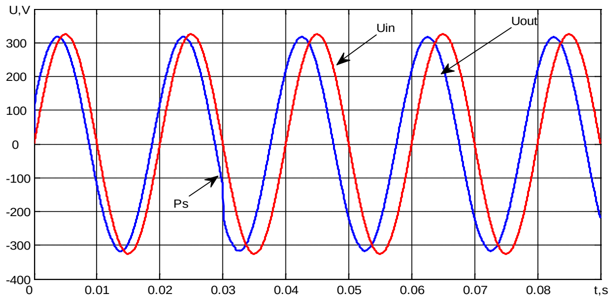

Figure 8. Input voltage curve (U_{in}), output voltage curve (U_{out}) and Ps point of switching phase shift from 24 degrees to 45.6 degrees.

How it can be seen from fig.8 overvoltage is missing. This confirms the advantage of transistors using instead of thiristors, because they can be closed at any time and thus simplify control scheme.

3. CONTROL SYSTEM OF POWER ELECTRONIC KEYS

Block scheme of control system consists from 5 modules (fig.9).

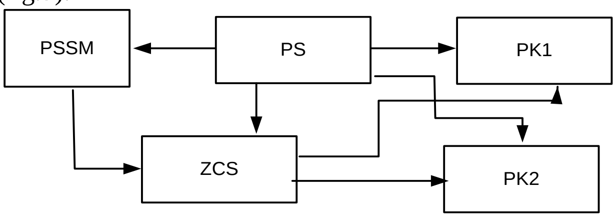

Figure 9. Block scheme of power keys management system. PSSM – phase shift selection module; PS – power source; PK1 – power keys outside of diodes bridges; PK2 – power keys inside of diodes bridges; ZCS – zero cross synchronization

a) PSSM – Phase shift selection module

This module provides possibility to select any of 14 steps of phase shift and set it. Its electrical scheme is given on fig.10.

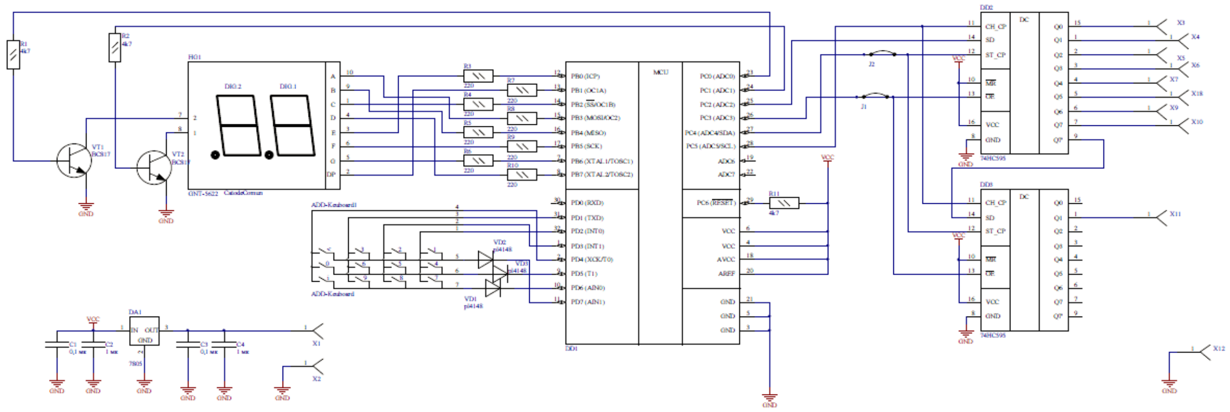

Figure 10. General scheme of PSSM

PSSM is supplied with keyboard for selection of necessary phase shift and enter it in accordance with developed algorithm shown on fig.7. After pressing “Enter” four outputs of device in correspondence with working algorithm are installed in “1”. In general this module is kind of coder from 15 in 9. It can be observed that for any position we have change only on one or two active outputs. This means that the losses due to switching process are less. The selected position of phase shift is displayed on digital screen.

b) PS – power source

Power source module provides galvanic separated supply of all keys. It consists of transformer with 32 windings and each of them has 12V.

c) PK1 – power key No.1

PK1 – these keys are used beside of diodes bridges. Their scheme is shown on fig.11.

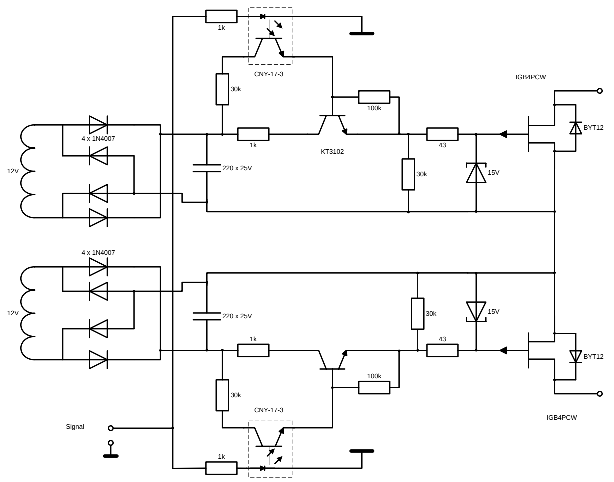

Figure 11. General scheme of PK1

From fig.11 it is obviously that for control of both transistors is enough one management signal due to using of optical separated transistor.

d) PK2 – power electronic key No.2

PK2 is using to switch corresponding diode bridges and to create a common point of all bridges. General scheme is shown on fig.12.

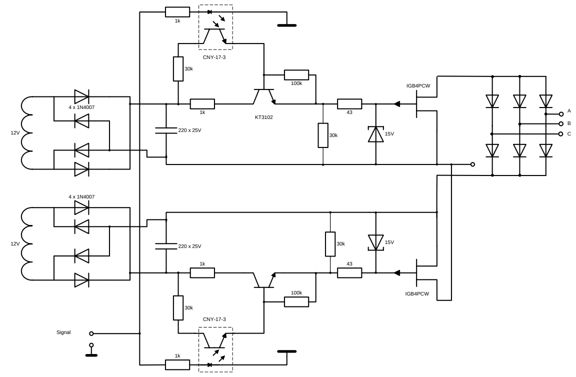

Figure 12. General scheme of PK2

From fig.12 we can remark that there is only a little difference between PK1 and PK2, and this difference consists in way of transistors connection.

e) ZCS – Zero cross synchronization

ZCS is used for applying and removing of control signals to power electronic keys only then voltage curve of respective phase cross zero point. The general scheme is shown on fig.13.

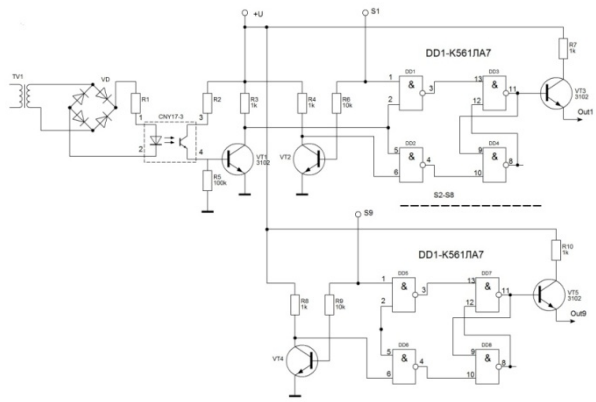

Figure 13. General scheme of ZCS

This module receiving signals from PSSM at inputs S1-S9 and then current curve cross zero point the current sensor TV1 applying these signals to the output Out1-

Out9. After, these signals are applied to the respective power keys in accordance with working algorithm. So, we exclude the overvoltage, voltage drop and over currents.

CONCLUSIONS

1. The new innovative technical solution of phase shift device realization, which in comparison with standard technical solution allowing decreasing the rated power up to 20% without using of capacitor bank connected in parallel and up to 50% with capacitor bank, is submitted.
2. The innovative electronic power system for switching of phase shift, which has rated power less on 34% and improved switch time in comparison with traditional solution, is presented.
3. The practical realization of whole power electronic switching system is elaborated and submitted.
4. The technical solution proposed in this paper does not exceed THD of 0.4% and has an improved time of switching. Beside, the overvoltage and voltage drop are missing.

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