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Investigation of the Operation Speed of AC Voltage Sensor

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***Abstract*-In the article the AC voltage sensor of industrial frequency – the signal former of the analogue controller with pulse-width modulation which, in its turn, controls the high-frequency electronic pulse AC voltage stabilizer, is considered.**

I. INTRODUCTION

Regulation of the sine-shaped AC voltage including its stabilization similarly as for DC voltage can be implemented applying a pulse regulator operating on the PWM principles [1,2]. But for stabilization system performing a good feed-back voltage sensor must be applied producing DC signal proportional to the magnitude of the AC sine-shaped voltage. At that to obtain a better stabilization the feed-back signal must follow the AC voltage changing with extreme processing speed.

Operation principles of such sensor can be different but in all cases the checked voltage is applied in form of the two-wave unidirectional voltage in output of rectifier [3]. Solution based on integrating RC-circuit is popular counting voltage across capacitor plates at the end of each wave. If diode is inserted in circuit of RC a DC voltage is proportional to the magnitude of the sine-shaped AC voltage but only if time constant of circuit is much smaller than the length of half-cycle of voltage considered. However, after fixing the level of signal capacitor must be discharged for proper considering of the next half-cycle. It is possible to apply for the goal analogue (on base of OP) and digital (ADC/DAC) integrating devices as well.

However, in all the presented realization cases input signal of sensor is obtained in sequence of discreet levels links of uni-polar voltages. Obviously, the duration of each link is equal to the half-cycle of voltage measured. As a result, such a feed-back signal has a stepwise changes but that is drawback for control of analogue PWM possible to arise a self-oscillations in system. To eliminate them it is necessary to use complemented sensor with inertial link which reduces processing speed. At that all these improvements are difficult for realization.

Taking into account all the above mentioned in this paper another version of sensor with simplest construction and much higher processing speed is described. In essence capacitive link can be supplied with DC signal and high frequency AC ripple but such solution also in some extent reduces processing speed in dynamics. Relations between ripple size, their frequency and time constant τ of the smoothing filter at parallel connection of capacitor and resistor can be described as [3,4]:

$$\tau = \frac{\frac{2\pi}{p} - \arccos\left(1 - \frac{\Delta U_{\%}}{100}\right)}{\omega \cdot \ln\left(\frac{1}{1 - \frac{\Delta U_{\%}}{100}}\right)}, \qquad (1)$$

where p is number of ripples in output voltage of diode rectifier scheme supplied with evaluated sine-shaped AC with angular frequency ω;

$$\Delta U_{\%} = \left(\frac{U_{max} - U_{min}}{U_{max}}\right) \cdot 100\%$$

is relative ripple size of rectifier's output voltage.

Expression (1) corresponds to filter capacitor discharging process from voltage U_{max} to U_{min}.

Fig.1 presents the computer modelling scheme for sensor with two-wave rectifier. Here the sensor is presented as voltage-down transformer with centre tap diode rectifier in secondary circuit. At primary voltage can be stepwise increased and decreased using for that supplementary transformer.

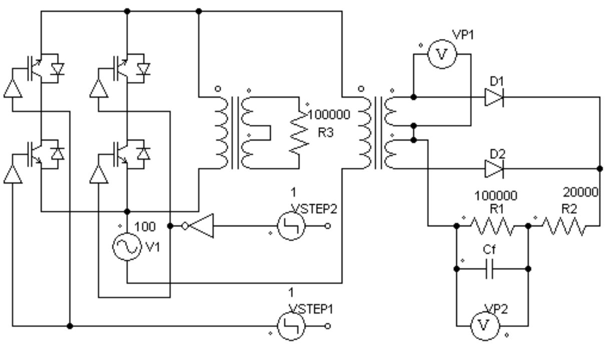
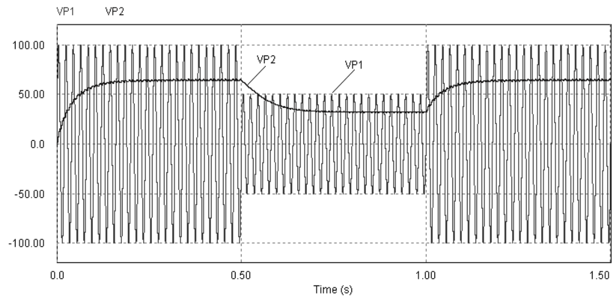


Fig.1. Scheme of computer modelling of sensor with two-wave rectifier

Parameters of R_1 and C_f (see Fig.1) are accepted in accordance with (1) at $\Delta U_{\%}$= 5% in stationary case. From diagrams Fig.2a,b it is seen that output signal VP2 in case of step-down of measured voltage is lagging for 9...10 cycles (Fig.2,a).

Accepting at output larger capacitor providing $\Delta U_{\%}$= 1%, processing speed is much worse (Fig.2,b). It can be concluded that for rising of processing speed capacitance must be decreased, but providing same relative ripple $\Delta U_{\%}$ with multiplication of ripple number *p* in cycle which corresponds to expression (1).

a)



b)

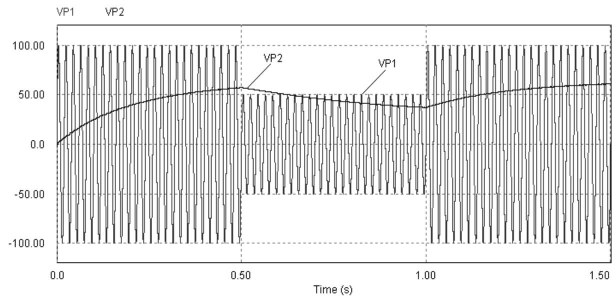


Fig.2. Investigation of sensor with two-wave rectifier in dynamics: a) dynamics response at step-down of input voltage and accepted $\Delta U_{\%}$=5%; b) dynamic response at accepted $\Delta U_{\%}$=1%.

II. OPERATION PRINCIPLE OF THE SENSOR AND ITS CONSTRUCTION

Fig.3 presents a calculated time constants at *p*=2, 4, 6, 10, 18. As comment it must be said that at *p*=10 and *p*=18 ripple level $\Delta U_{\%}$= 5% can be obtained without any filtering devices.

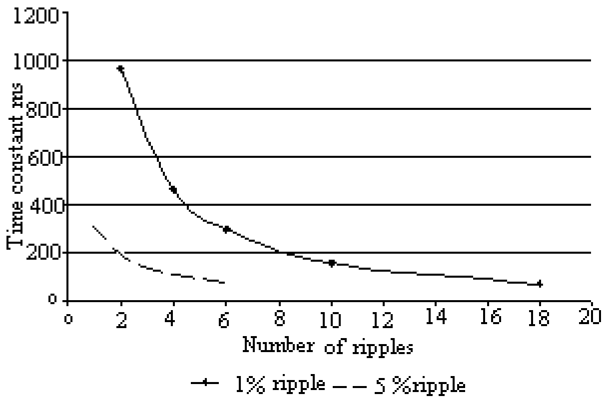


Fig.3. Time constant versus number of ripples

As it can be seen from Fig.3, processing speed can be improved essentially rising number of ripples up to 18 (in 20 times compare to two ripple case). Such rising of ripple number can be reached using multi-phase rectifying schemes:

p=4 can be reached in four-phase one-wave scheme;
p=6 in three-phase bridge scheme;
p=10 in five-phase bridge scheme;
p=18 in nine-phase bridge scheme.

Artificial obtaining of small power multi-phase rectifying schemes is possible on the base of symmetric multi-phase voltage which can be obtained from single-phase measured voltage using bridge mode phase shifting scheme (Fig.4).

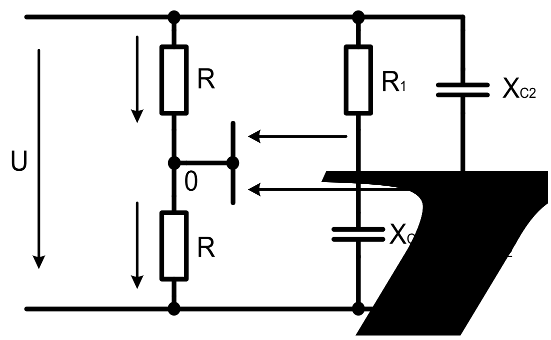


Fig.4. Scheme of bridge mode phase shifting device

When the bridge is operating in no-load regime:

$$\dot{U}_{01} = \left(\frac{\dot{U}}{2}\right) \cdot e^{-j\psi_1} \qquad (2)$$

and

$$\dot{U}_{02} = \left(\frac{\dot{U}}{2}\right) \cdot e^{j\psi_2}, \qquad (3)$$

where ψ is phase shift of voltage U_0 in respect to input voltage U. From the vector diagrams for phase shifting bridge

$$\left|\psi_1\right| = \pi - 2 \cdot \left|\varphi_1\right|, \text{ where } \left|\varphi_1\right| = arctg\frac{X_{C1}}{R_1};$$
$$\psi_2 = 2 \cdot \left|\varphi_2\right|, \text{ where } \left|\varphi_2\right| = arctg\frac{X_{C2}}{R_2}. \qquad (4)$$

Calculating by (4) a parameters of phase-shifting RC link in accordance with the requested number of phases in symmetric voltage system, it is possible to obtain the multi-phase rectifiers for operation in sensor mode at no-load conditions [5]. As an example in Fig.5 computer modelling scheme is presented with the correspondent input VP1 and output VP2 voltage diagrams for five-phase bridge rectifier. Initial transient process can be observed in duration of one cycle and after it a stationary operation begins.

Considering processing speed of the presented five-phase rectifier a computer modelling at step-up and step-down input voltage leaps was elaborated (Fig.6). From Fig.6 we can see that the output voltage follows to changes of input one with minimal delay. At that resistance of resistor R5 for considering a no-load condition was accepted as: $R_5 >> R_i$ where R_i is the resistance of the phase-shifting links.

III. LOADED OPERATION OF ELABORATED SENSOR

As it was declared for simplification, a no-load regime was accepted. Such assumption means that at really loading of sensor obtained simplified phase shifting angles should not be preserved. Therefore, it is necessary to calculate sensor at some certain loading inside it which means that in hereafter.

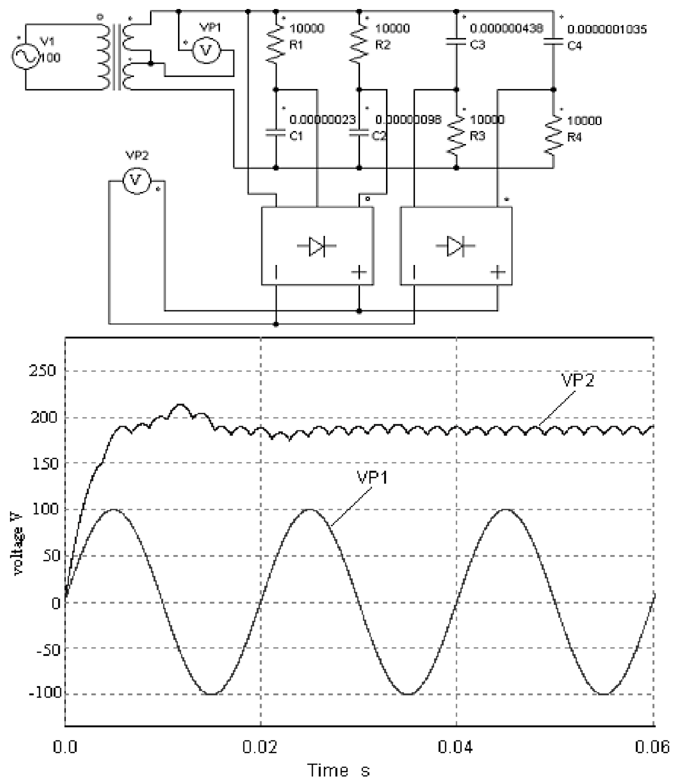


Fig.5. Modelling scheme of five-phase rectifier and input-output voltage diagrams

Analysis of loaded artificial scheme of multi-phase voltage at loading is rather complex task. The simplest way is to calculate parameters of phase-shifting bridge link (on base of given phase shifting angles), loading each link of shifted voltage with resistive load across the diagonal of the bridge.

Fig.7 shows the analysed scheme of phase-shifting junction with one phase-shifting RC link. Voltage measured is connected through voltage-down transformer the secondary winding of which is centre tapped.

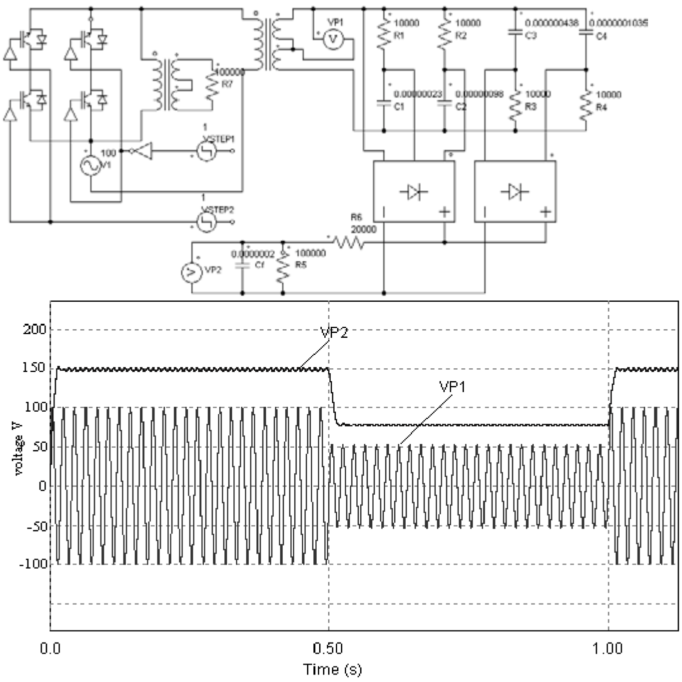


Fig.6. Modelling scheme of five-phase rectifier-sensor and output signal diagram at stepwise change in input voltage

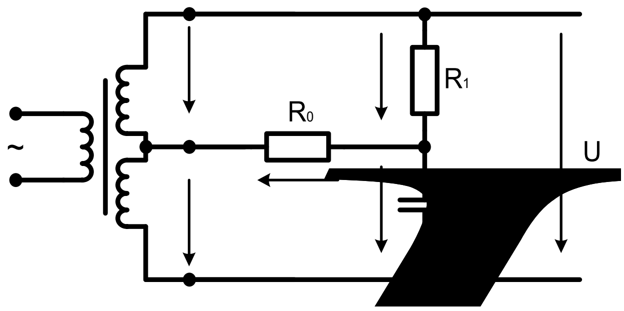


Fig.7. Calculation scheme of loaded phase-shifting link

Calculating the scheme applying Kirchhoff's Law with symbolic method we can obtain [6]

$$\dot{U} = \frac{\frac{\dot{U}}{2}\left(R_1R_0 + jR_0X_{c1}\right)}{jX_{c1}\left(R_1 + R_0\right) - R_1R_0} . \quad (5)$$

Converting in more convenient form without imaginary numbers in denominator

$$\dot{U}_0 = \frac{\dot{U}}{2} \cdot \frac{R_0^2\left(X_{c1}^2 - j2X_{c1}R_1 - R_1^2\right) + R_0\left(R_1X_{c1}^2 - jR_1^2X_{c1}\right)}{\left(R_1R_0\right)^2 + \left(R_1X_{c1} + R_0X_{c1}\right)^2} \quad (6)$$

Accepting in (5) $\dot{U} = U$ where U is a real number phase shifting angle ψ of U_0 in respect to the voltage U is

$$\psi = arctg\frac{\mathrm{Im}\left(\dot{U}_0\right)}{\mathrm{Re}\left(\dot{U}_0\right)}. \qquad (7)$$

It means that in accordance to (6),(7) the necessary parameters of multi-phase voltage system can be obtained taking as basis necessary angles ψ_1, ψ_2,... so on. Multi-phase rectifier scheme with the parameters chosen in accordance with the above given equations and internal load is presented in Fig.8. For the better equalization of shifted voltages U_{01}, U_{02} ...so on, in practical calculations can be proposed choice the resistance R_0 equal in all links and keep $R_0 >> z_i$, where

$$z_i = \sqrt{R_i^2 + X_{ci}^2};$$

can be proposed also to keep $z_i \approx$ const for all links. But $R_0 << R_F$, where R_F is probable load of multi-phase rectifier.

In such way the obtained artificial voltage system voltages of links U_{01}, U_{02} ...U_{0i} will be proper shifted but also rather different by their magnitude (see Fig. 9,a). For their equalization a load resistors of links R_0 can be realized as voltage dividers taking to rectifier symmetric multi-phase voltages (see scheme 8 and diagram Fig.9,b). Fig.9,c demonstrates the obtained output DC signal VP7 connected with measured voltageVP1.

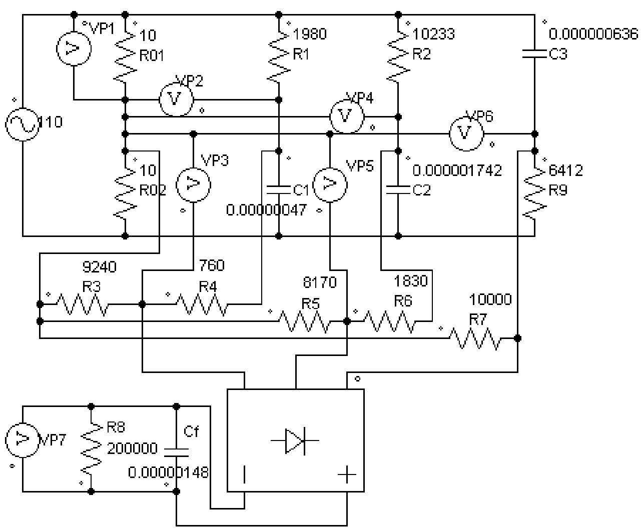


Fig.8. Scheme of multi-phase sensor with internal load

For better equalization of rectifiers input voltages the internal load resistors were realized as voltage dividers with different nominal (see. Fig.8). The above described scheme with inside loading was investigated also in dynamics (Fig.9).

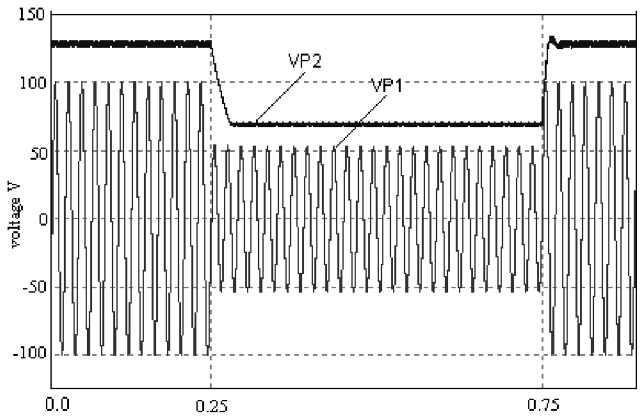


Fig.9. Investigation of the scheme in dynamics

Dynamic response at step-drop of input voltage lasts some two periods of input voltage. At step rising of input voltage response is much faster – less as one cycle time. Optimizing the output filters of rectifier it is possible to get much faster processing at smaller ripple range in stationary operation case.

At the end it must be complemented as optimal number of phase for rectifier also is subject of improvement of the scheme.

IV. CONCLUSIONS

1. Applying a multi-phase rectifier is useful for obtaining a fast processing sensor for measurment of input sine-shaped voltage magnitude.
2. Obtaining multi-phase symmetric voltage can be realized using phase-shifting RC bridges.
3. For lessening of sensor's external load influence it is preferable to install an internal load of RC phase-shifting links.
4. Optimization of number of phases as also realization mode of filters at output of sensor is optimization task actual for elaboration of sensor.

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