FULL PAPER
International Journal of Recent Trends in Engineering, Vol 2, No. 5, November 2009

The Stabilization of AC Voltage: The need for stabilization, its special feature, some design aspects

Dr. Abdel-Rahman Al-Qawasmi[1] and Dr. Ayman Al-Lawama [2]
[1] Philadelphia University/Communications & Electronics Department, Amman, Jordan
Email: qawasmi@philadelphia.edu.jo
[2] Mutah University/ Electrical Engineering Department, Karak, Jordan
Email: ay_lawama@yahoo.com

***Abstract*—Even with the fluctuations in the network voltage, the AC voltage level at the customer terminals must maintain stable. The stabilization process offers a compensation holding the output voltage to protect the main equipments. This paper presents the merits of Discrete Stabilization as compared to phase and two-level voltage regulations. This paper proposes using of more complex block to the multi-block discrete stabilizer in order to increase the number of steady states, and consequently, decreasing the error in voltage regulation for the customer mains.**

***Index Terms*— voltage regulation, discrete stabilizer, transforming elements, multi-block stabilizer**

I. INTRODUCTION

Most of the important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer's processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment. However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. A voltage quality problem relates to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions).

Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched, also contribute substantially to power quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components. Between the different voltage disturbances that can be produced, the most significant and critical power quality problems are voltage sags due to the high economical losses that can be generated. Short-term voltage drops can trip electrical drives or more sensitive equipment, leading to costly interruptions of production [1].

This paper mainly describes the effect of voltage deviation on electrical loads. It is the least critical in case of the devices with heating elements (like electric stove, heaters, electros-teapot, etc.) in which any deviations simply change only the operating time. Lighting plants, on the contrary, are very sensitive to instability of the line voltage:

the luminous flux of incandescent lamps is proportional to the relative change in voltage to a degree of 3,61, voltage leads to 17% decrease in the luminous flux, and a similar increase in line voltage reduces the service period of such lamps to 1/2. The service period of gas-discharge tubes is reduced on the average of 2-3% with 1% increase in the voltage. To a certain degree the same effect is observed in "energy-effective" compact fluorescent lamps.

The consumption of electric power by everyday loads depends substantially on the value of the line voltage. When it exceeds the nominal voltage by 5%, the consumption of the active and reactive power of refrigerator (for example) increases by 6 and 28%, respectively. Generally, for all loads containing induction motors, a significant reduction in voltage might lead to a burning of motors' windings. Office equipments, like computer, suffer from the poor quality power supply. Many computer producers guarantee the normal operation of their production with the stability of the supply voltage, the steady-state regime in the range ±10% and short-term (up to 30 ms) deviations of +15% or -20%.

Voltage in low-voltage distribution network, from which the majority of the electrical equipments are fed, is not constant. Depending on distance from the transformer substation and the degree of the line overloading, the specific permissible limit of voltage deviations in each country is regulated by the appropriate standards. According to the Jordanian standard "the normal and maximum permissible values of the steady state variation of voltage at consumer terminals are equal to ±5 and ±10% of the nominal voltage, respectively [2,3].

There are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line-conditioning systems that suppress or counteracts the power system disturbances.

II. VOLTAGE REGULATIONS IN AC SYSTEMS

Utility components (like computers) should be connected to AC mains with at least a voltage stabilizer. A voltage stabilizer is a device that will maintain the AC output level stable, even with fluctuations in the input voltage. Therefore if the network shows voltage surges, brownouts or over voltages, the stabilizer will offer a compensation holding the output voltage, therefore, protecting the main equipments.

As these components are fed from the public electrical network, network disturbances will impart directly its functioning, and may even cause the burning out of some components.

In the absence of the voltage stabilizer, the customer voltage U_2^* will coincide with the network voltage U_1^*, corresponding to the straight line OAMB in Fig. 1 (the voltages are given in per unit with base voltage of 220V). Note that only at point M when U_1^* = 1, customer is supplied with nominal voltage.

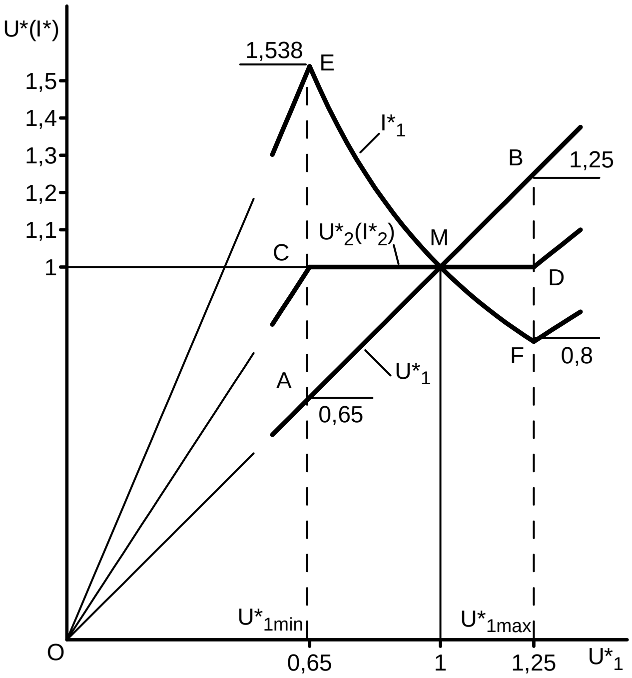


Figure 1. The input voltage variation for ideal stabilization process.

Ideal stabilization maintains the output voltage fixed on the nominal level (U_2^* = 1) with the variation of the input voltage in the range from the lower limit $U_{1\min}^*$ (0.65 pu) up to the upper limit $U_{1\max}^*$ (1.25 pu). In section, where $U_1^* < U_{1\min}^*$, the input voltage is linearly varied (line OC), and the relationship U_2^* = f (U_1^*) corresponds the broken straight line OCMD.

If the load is active and constant, the relative value of output current I_2^* (in pu with base value equal to the rated current of load) is completely in accordance with the relationship

$$U_2^* = f(U_1^*) \tag{1}$$

For simplicity, stabilization is assumed to be ideal i.e. the efficiency is equal to 1 ($P_1^* = P_2^*$ = 1). In stabilization zone (0.65≤U_1^*≤1.25), the input current must change according to the formula:

$$I_1^* = P_1^* / U_1^* = 1/U_1^* \tag{2}$$

It is inversely proportional to the change in the input voltage (the curve FME).

For U_1^* > 1, the input current is less than the output and at point F it reaches its minimum:

$$I_{1\min}^* = 1/U_{1\max}^* = 1/1.25 = 0.8; \tag{3}$$

For U_1^* < 1, the input current is more than that of the output and reaches the maximum at point E:

$$I_{1\max}^* = 1/U_{1\min}^* = 1/0.65 = 1.5358 \tag{4}$$

Thus, in the absence of the stabilizer, if the input current is maximum (1.25 pu) at maximum input voltage, then with the presence of stabilizer the input current is maximum at minimum input voltage and can substantially (in this case more than 1.5 times) exceed the rated load current, which must be considered in the cross-sectional calculations of the feeder.

III. THE REALIZATION OF VOLTAGE REGULATION

Basically, stabilizers are designed on Ferro-resonant transformer basis (like the stabilizers of the type RT, produced by the firm AEES, France) or on a servo-mechanical basis (model SMT 15 for the same firm). A simple arrangement is given in Fig. 2, the stabilization of the output effective voltage is related to the phase regulation (PR) corresponding to the triggering angle of the electronic switch placed on the output (or input) of the autotransformer (AT). Note that AT is always stepping up transformer i.e. $K_{тr}$=1/0.65=1.5385, so that it is possible to increase the input voltage when the network voltage is dropped down.

However, in this arrangement, a strong distortion of output effective voltage and current will take place. Thus, if the form of the half-waves of these values is sinusoidal at the lower limit of the feeding voltage (see the Table), then with the increase of U_1^* it begins to be distorted: at point M (in Fig. 1) the coefficient of harmonics U_2^* (I_1^*, I_2^*) reaches 72.5%, and the upper limit ($U_1^* = U_{1\max}^*$) exceeds 90.5%, which is absolutely unacceptable for both the consumer and the power line.

Good results can be obtained, if an additional switch is added to the structure of Fig. 2 a (as shown by the dotted line). In this case, the possibility of obtaining one more transformation ratio of $К_{тт}$=0.8 is achieved, and phase regulation is conducted between two levels of voltage (TLR). Within the range of stabilization, both of the output voltage (or current), and input current have a sinusoidal form (the form of supply voltage, which according to standards, must be closed to the sinusoidal form). However, in the middle of this range, the form of all these values is distorted (see the Table). Thus, at point M (U_1^* =1) the coefficient of the harmonics of the output voltage (or current) composes 16.7%, which is almost 4.5 times less than that in the case of PR. At the same time the coefficient of the harmonics of the input current is reduced to 57.8 (only in 1.28 times). By increasing the number of levels (between which a phase regulation may takes place), it is possible to, substantially, obtain good results, but some certain distortions of the output voltage and currents, nevertheless, are remained.

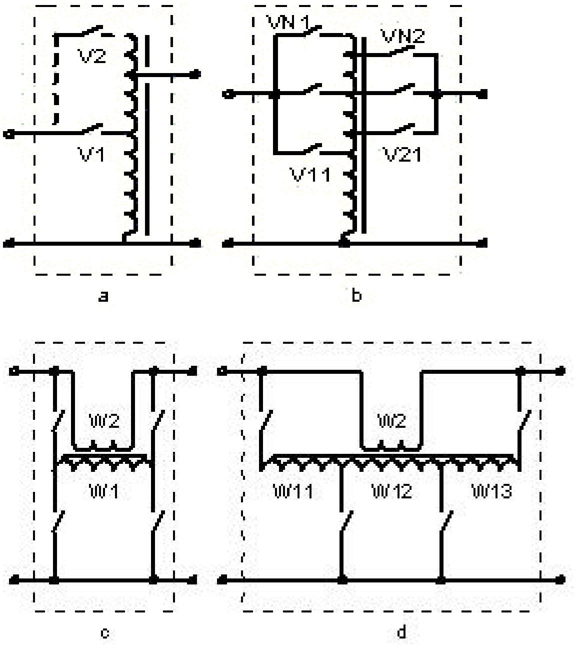


Figure 2. The autotransformer and switching elements in the stabilization structure.

There is a class of alternating voltage stabilizers, in particular - stabilizers, in which the converter itself doesn’t introduce any distortions. It is the so-called discrete stabilizers (DS).

IV. VOLTAGE STABILIZERS WITH A DISCRETE CHANGE IN THE TRANSFORMATION RATIO

Specifically, on the principle of discrete transfer from one voltage level to another, different types of AC stabilizers have been recently constructed. The transfer is achieved by switching N electronic switches upon the transfer of the current through zero. In this case the form of the output voltage and the input current do not undergo distortions (see the Table), but they are accompanied with certain errors.

The permissible error limit for the customer is ensured with the assigned range of a change in the input voltage due to the selection of the parameter J – the number of possible discrete states of the system in accordance with the relation [3]:

$$J = \lg\left(\frac{U_{1\max}}{U_{1\min}}\right) \Bigg/ \lg\left(\frac{U_{2\max}}{U_{2\min}}\right). \qquad (5)$$

Usually J does not exceed 10-12. Theoretically, with the change of U_1^* within the same limits (0.65-1.25), an error in the order of +4% may be occurred at *J*=8.

Electronic switches are, generally, located either on the primary side of the AT (VOLTRONIC 4500 stabilizers, firm AROS, Italy) or on the output (Re2 stabilizers, firm SALICRU, Spain). In both designs, the number of possible transformation ratios is unambiguously equal to the number of switching elements (*J*=*N*).

In some previous works it was proposed to divide the switching elements into two groups, one is located on the primary, and the other on the secondary side of AT (Fig. 2, b). In this case, the total number of switching elements is equal to the sum of switches in the group (N=N1+N2), the number of the possible states of the system is determined by the product (J=N1×N2). For example, with N = 9 in the above-indicated stabilizers J=9, while here J=9 is ensured by only 6 switches (N=6=3+3; J=3×3=9). On the contrary of that, it is possible to preserve the same number of elements, as in prototypes (N=9), to obtain better stabilization (N=4+5; J=4×5=20 >> 9).

TABLE 1
HALF-WAVE DISTORTIONS FOR PR, TLR, AND DS STABILIZATION

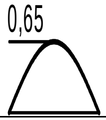
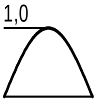
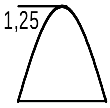
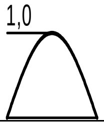
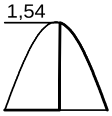
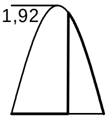
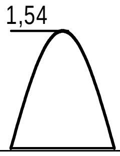
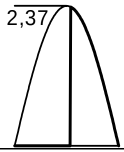
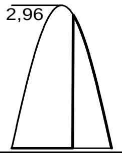
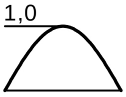
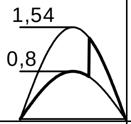
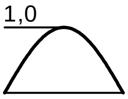
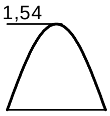
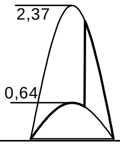
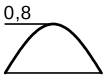
PR	Point	A	B	C
	U_1^*			
	$U_2^*(I_2^*)$			
			97°	111,3°
	I_1^*			
	Kr2, %	0	72,5	90,5
TLR	Point	A	B	C
	$U_2^*(I_2^*)$			
			118,5°	
	Kr2, %	0	16,7	0
	I_1^*			
	Kr1, %	0	51,8	0

Fig. 3 gives the relationship $U_2^*(I_2^*)=f\ (U_1^*)$ and $I_1^*=f\ (U_1^*)$ for the discrete stabilizer with J=9. It is shown that with the variations of the input voltage by 35% down and by 25% up relative to the nominal value, the output voltage is supported with an error of ±3.6% only, which is acceptable for most of the practical applications. Adding one switch only (N=7=3+4) obtaining J=3×4=12, which corresponds substantially to a smaller error in the order of ± 2.7%.

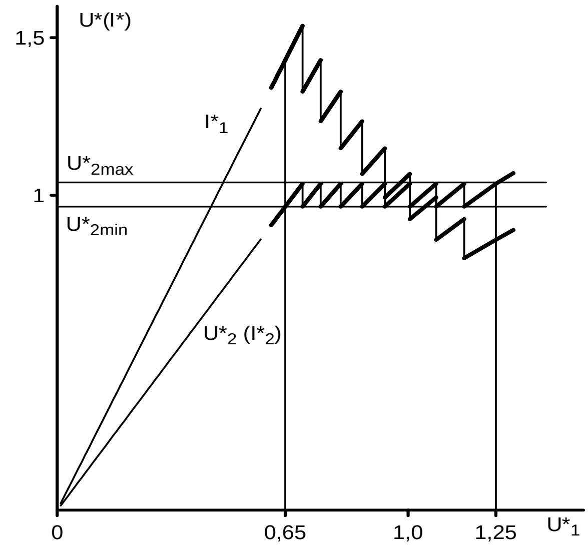


Figure 3. The characteristic of the input and output voltage for the discrete stabilizer.

Notice that, the presence of vertical sections in the characteristic $U_2^*(I_2^*)=f\ (U_1^*)$ does not indicate any dangerous voltage surges: switching occurs at the moment of passing the power current through zero, i.e., the system smoothly switches to the supply from other voltage (more or less in γ times, where $\gamma = U_{2\max}^*/U_{2\min}^*$ =1.036/0.964≈1.075). In this case the input current is considerably changed (in γ^2 times i.e., 1.075^2=1.155 times).

The same value of J can be obtained by using two structures. The first assumes the arrangement of switches in the power current contour, while the realization of switching of the power current can be achieved with one or two groups of switching elements. The second approach recommends the carrying out of the switching elements from the contour of power current, as the switches themselves are selected for currents, which are less than the load current in 3-4 times. Fig. 2.c depicts one unit of realizing a stabilizer on this principle. It is an ordinary bridge structure with two-windings boosting transformer. In this block the simultaneous operation of a pair of switches in three combinations is allowed. Therefore, the block has three stable states (J=3) - boosting voltage, direct transmission of electric energy from the source to the load and voltage reduction. The complex of two of such series-connected blocks enables obtaining 9 states ($J=J_1\times J_2=3\times3=9$). If it is necessary to decrease the stabilization error, then three such blocks are to be connected (J=3×3×3=27). In this case the sum of installed capacity and, correspondingly, the mass of all boosting transformers will not change significantly, since each subsequent boosting transformer has a mass of, approximately, three times less than the previous.

The conducted investigations in [4] showed that (at equal value of J), the installed capacity of all electromagnetic elements of the executive structure of the stabilizers, which are built on the basis of carrying out of switches from power current contour is somewhat more or less than the installed capacity of the variable autotransformer in the structure of Fig. 2 b, depending on the boundaries of the range of the input voltage variation.

This paper proposes using more complex block to the multi-block stabilizer. This block contains four-winding boosting transformer in the composition of the modernized bridge structure (Fig. 2, d). At the same number of switches (N=4), it has more steady states (5) than in the case of ordinary bridge (3). In connecting this block with the ordinary bridge it is possible to obtain 3×5=15 steady states, i.e., decreasing the error in voltage regulation for the user mains [5, 6, 7, 8].

CONCLUSIONS

Based on the analysis conducted in this work, the following conclusions can be made: -

1- With Discrete Stabilization, minimum additional distortions are introduced to the form of voltage.

2- For the Discrete Stabilization, the permissible error limit for the user is ensured with the assigned range of a change in the input voltage based on the selection of the parameter J.

3- Obtaining the desired value of J at a minimum value of N is possible only with the decomposition of elements into groups.

4- With the design of discrete stabilizers (as all stabilizers in general) it is necessary to design them for maximum input voltage and maximum input current, which is observed at a minimum input voltage.

5- Voltage stabilizer provides its user with the desired conditions for the electrical apparatus, but in the same time it creates a problem of instability for other consumers connected to the same network. Therefore, it is necessary to keep the number of consumers that are connected to the network through a stabilizer as minimum as possible.

REFERENCES

[1] C. Melhorn, T. Davis, G. Beam, Voltage Sags: Their Impact on the Utility and Industrial Customers, IEEE IAS Trans. on Ind. Appl., Vol. 34, No. 3, May/June 1998, pp. 549-558.

[2] I. Badran, General Standards & Regulations for Non-Industrial Electrical Installations, Jordan Electricity Authority, Amman, 1987.

[3] V. Tonkal, Alternating voltage regulators and stabilizers with undistorted output voltage,/3rd Power Electronics Conference, Budapest'77, Vol.6.6.15, pp. 1-12.

[4] V.A. khalikov, A.G. Mozharovskiy, Calculation of the installed capacity of the transforming elements for the AC discrete stabilizers, Journal of electrodynamics, 2004, №1, pp.30-35.

[5] S. D. Round and D. M. E. Ingram, An Evaluation of Techniques for Determining Active Filter Compensating Currents in Unbalanced Systems, European Power Electronics Conference, Trondheim, Norway, pp 4.767-4.772, 1997.

[6] Avedes M, Hafner J, Heumann K., Three-phase four shunt active filter control strategies, IEEE trans. on power electronics, Vol.12, 1977, pp.311-318.

[7] E.Akawa, A.Uedo, M.Yamada, Fast-Acting voltage compensator with an active filter. IPEC'90 trans., pp.985-992.

[8] H. Akagi, Control Strategy and Site Selection of a Shunt Active Filter for Damping of Harmonic Propagation in Power Distribution Systems, IEEE Transactions on Power Delivery, Vol. 12, No. 1, 1997, pp. 354-363,.