

Novel approach to control of active rectifier during voltage dips

Y E Shklyarskiy, A I Bardanov and A Y Shklyarskiy

St. Petersburg Mining University, 2, 21 line of Vasilievsky Island, St. Petersburg, 199106, Russia

E-mail: bardanov.alexey@gmail.com

Abstract. The paper is about voltage oriented control (VOC) of an active rectifier during short periods of voltage dips. Most of voltage dips are caused by short circuits in one line or between two lines. This leads to the three phase voltages unbalance. While power grid is unbalanced, the voltage vector is rotating, but its hodograph of the generalized voltage vector is not a circle. The control system of an active rectifier is orienting the current vector in the direction of the voltage vector. Because of the specificity of the control system, these conditions lead to the harmonic distortion of rectifier's currents. In the article, the mechanism of forming the currents is circumstantially described. A MATLAB Simulink model of an active rectifier and simulation results are presented. The solution of the described problem is to improve the control system to achieve sine wave currents. The novel approach to the active rectifier control is proposed and the efficiency is confirmed by simulation results.

1. Introduction

One of the most important problems of the power quality in our days are voltage dips. According to IEEE 493-2007 definition voltage dip is "a short duration reduction in rms voltage which can be caused by a short circuit, overload or starting of electric motors". Statistical data from different countries shows that this is very common event [1]. Usually the duration of voltage dips is more than 50 ms so they are dangerous for continuous production because they can lead to its interruption.

For example the compressors for gas transportation in one of the Norway stations in the Nord sea shore suffered from voltage dips with duration from 50 to 150 ms [2]. The power of one compressor is more than 42 MW so to prevent dangerous effects of pressure decrease during voltage dips, the protective relay has to stop the motor work and a gas transport process. Every single interruption of the compressors work led to financial losses. To solve this problem, specialists from the university modified the control system of the gas compressor's drive.

The metal rolling mills are driven by synchronous electric motors with a power of 10-15 MW. The speed adjust system of these electrical machines is very sensitive to voltage dips. Emergency stops of rolling mills are a reason of workpieces stuck into the machine. Restart of the process in this case takes more than two hours. To overcome voltage dips engineers used active rectifiers to control the drive's energy consumption or to compensate reactive power while grid voltage is low [3,4].

Papers also give examples of voltage dips' negative influence on the oil production process and railway rolling stocks that are powered from the electrical grid [5–7].

All cases mentioned above are connected because of the variable-frequency drive. If the diode rectifier connects drive's DC-link that usually contained capacity to the grid, diodes are controlled by voltage differences between line voltages and DC-link voltage. Low line voltages cannot open



rectifier's diodes so DC-link voltage declines [8]. When it achieves a critical level, the relay disconnects the drive from the power grid and the motor stops.

To prevent this situation, the active rectifier can be using. A common aim of active rectifier's setting up is power quality improvement by sine-wave current consumption. However property of DC-link voltage control is very useful while voltage dips. Often the voltage oriented control (VOC) technique is used to governance an active rectifier but while grid unbalanced (it is true for 80% of voltage dips) this technique leads to input currents distortion. Further in the article the mechanism of occurrence of this problem is considered and the way of its solution is offered.

2. Methods

Principals of voltage oriented control is well known and completely described in literature [9,10]. Since that, only a brief overview of VOC is presented below. Key points that are most important for understanding proposed solution are noted.

2.1. VOC of active rectifier principals

The idea of VOC control is to form input currents i_{ar} by making voltage difference between grid voltages v_{sys} and self-voltage source v_{ar} . The equivalent circuit is presented in figure 1. This approach requires the inner voltage source and usually the voltage inverter with wide pulse modulation (WPM) is used. Different modes such as reactive power or high harmonics compensation are possible, but in the paper only the rectifier mode is considered. The vector diagram of these mode is presented in figure 2. It is seen that in the rectifier mode there is only active input current so the rectifier power factor is 1 (clause to 1 in real devices).

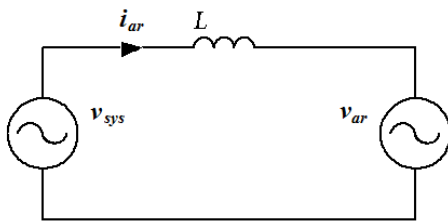


Figure 1. Equivalent circuit of an active rectifier

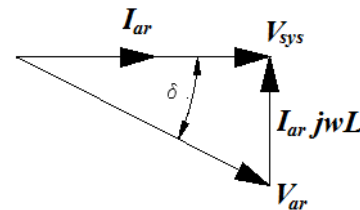


Figure 2. Diagram of voltages and currents of an active rectifier

VOC deals with Clark and Park transformation [11,12] to create inverter voltage reference ($v_{ar d}$ and $v_{ar q}$) and the d axis of rotating dq coordinate system routes to the voltage vector. There are two control loops in the system: the inner currents control loop (figure 3) and the main DC-link voltage control loop. The difference between actual DC-link voltage and reference voltage comes to input of DC voltage PI regulator that generates active current reference $i_{ref d}$. Since the rectifier mode is considered as the reference for reactive current $i_{ref q}$ is zero.

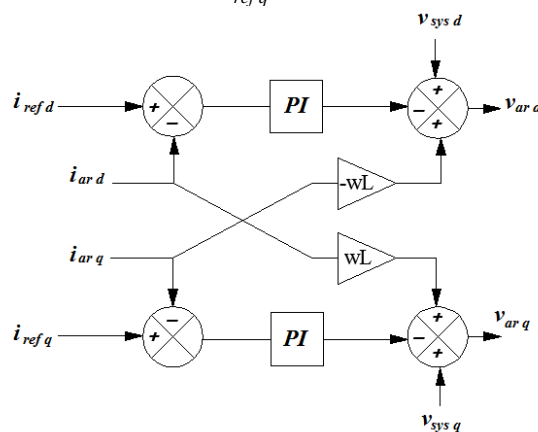


Figure 3. Structure of current control loop

Differences between actual currents and references come to PI controllers. Outputs of controllers are references for inverter voltage. To prevent mutual influence of different currents components, the control loop includes crossed links. It is vital to the control system that the current control loop is much faster than the voltage control loop.

Summing up the VOC system forms of the generalized current vector that it is directed as a generalized voltage vector, and its absolute value is proportional to the drive active power. In a steady state, this condition leads to constant power flow [13], that matches with the energy consumption of the motor.

2.2. Proposed control method

It was mentioned above that less than 20% of voltage dips is balanced. Let us consider that Clark transformation is applied to the set of unbalanced voltages. Projection of the generalized voltage vector of the unbalanced grid to $\alpha\beta$ frame is a rotating vector, but its hodograph is ellipse (further big and small ellipses of semi-axes are noted as a and b). For every ellipse there is a canonical coordinate system (that is noted as $\alpha_u\beta_u$ for voltage and $\alpha_i\beta_i$ – for currents) where the equation (1) is true [14]:

$$(u_\alpha/a)^2 + (u_\beta/b)^2 = 1. \quad (1)$$

Since Clark transformation projects only components of positive and negative sequences, it is easy to prove that in a sine mode (frequency is ω) components of generalized vectors are changed as:

$$u_\alpha = a \cos(\omega t); u_\beta = b \sin(\omega t). \quad (2)$$

The opposite statement is also true: if components of the generalized vector are sine-waves then electrical grid values are not distorted.

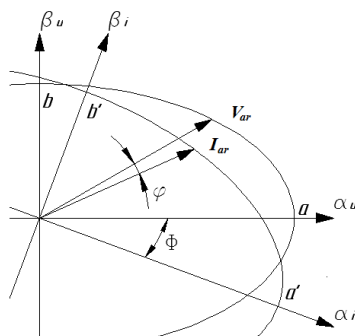


Figure 4. Non constant power flow mode

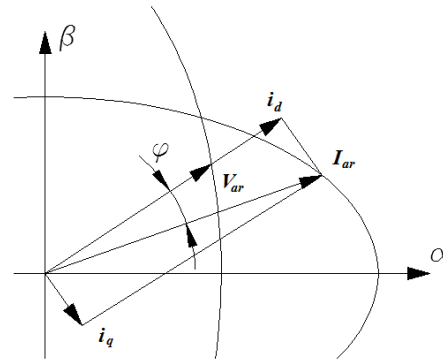


Figure 5. Constant power flow mode

Voltages unbalanced constant power flow has to be provided. Let us consider a general case (figure 4) when voltages and currents are unbalanced and sine-waved, so the equation (2) is true for both. There are many variables such as angles between vectors (φ) and coordinate systems (Φ) so the solution is not taken easy. The problem is much simple with an assumption that I_{ar} and V_{ar} have the same canonical frames. Power flow (noted p) is dot product of these vectors so the expression is:

$$p = (aa' + bb')/2 + (aa' - bb')\cos(2\omega t)/2. \quad (3)$$

Equation 3 contains constants of two components: the constant one and the variable one. It is clear that the condition, when the variable component disappears, is:

$$aa' = bb'. \quad (4)$$

It is showed in figure 5 that while voltages unbalanced the constant power flow and sine-waved input currents yield, when the current vector contains both d and q components. When semi-axes of voltage locus (a and b) are known [15], it is easy to calculate semi-axes values of current hodograph if power consumption is known. To calculate power consumption, it is possible to use $i_{ref d}$ value that comes from the voltage PI controller:

$$p = V_{dc} i_{ref d}. \quad (5)$$

It is easy to obtain references for the active rectifier's current control loop with equations (3), (4) and (5). For the current rotation angle (noted ωt) of dq frames, direct and quadrature components of currents are calculated as:

$$i_{ref d} = (i_{\alpha} v_{\alpha} + i_{\beta} v_{\beta}) / |V_{ar}|; i_{ref q} = (i_{\beta} v_{\alpha} - i_{\alpha} v_{\beta}) / |V_{ar}|. \quad (6)$$

Further it will be shown that this condition leads to sine-wave currents during voltage dips.

2.3. Computer model

To study the active rectifier work, while grid unbalanced, the dips computer model was created with MATLAB Simulink software. The block diagram of the model is presented in figure 6.

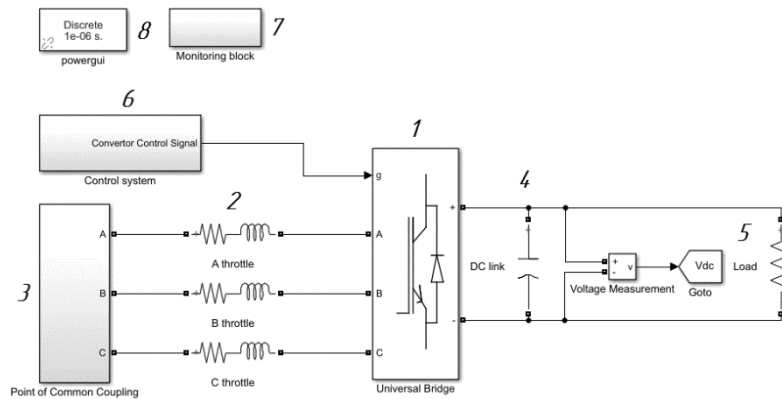


Figure 6. Blok diagram of computer model

The first is a standard universal bridge block that models the voltage inverter. Number two shows a group of a throttle. The point of common coupling is modelled by block number 3. Constant load is considered by active resistance (5) that is connected to DC-link. A unit control system is into block number 6. Blocks 6 and 7 are added for simulation needs. Simulation results for both the common VOC control system and the proposed control system are presented in the next section.

3. Simulation results

Here results of simulation are shown and fully described. First let us take a look to active rectifier's work with the balanced grid, then results are obtained during voltage dips.

3.1. Balanced grid voltages

Normal active rectifier works results are presented in figures 7 and 8.

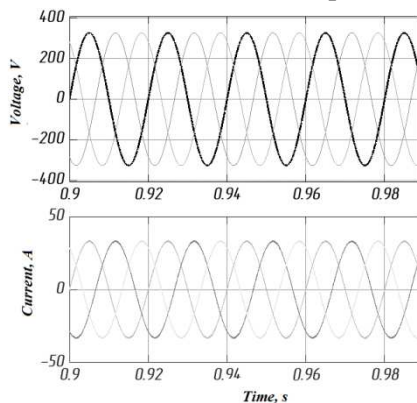


Figure 7. Balanced voltages and currents

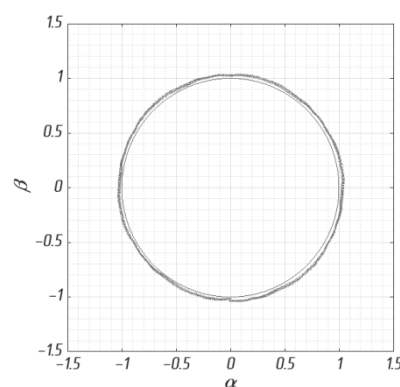


Figure 8. Hodographs of voltage a current vectors p.u.

In this mode, currents are the same as voltages; so the power factor is 1. Hodographs of voltage and current vectors are circuits. Here and further currents hodograph looks thicker because of ripples on switching frequency.

3.2. Classic VOC work during voltage dip

First line voltages are half decreased. Simulation results for this mode are presented in figures 9 and 10.

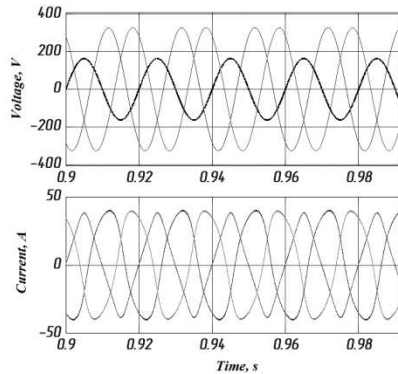


Figure 9. Unbalanced voltages and distorted currents

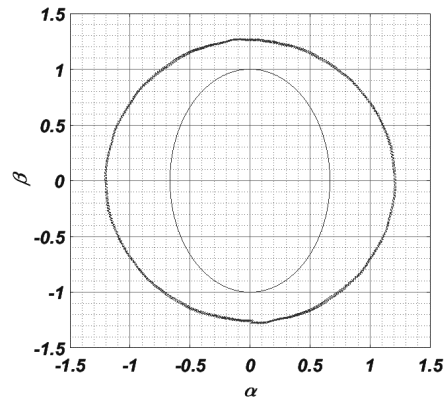


Figure 10. Hodographs of voltage and current vectors p.u.

In this mode, the voltage vector rounds with variable speed. Near the long ellipse's semi-axes, the vector rotates slowly than near the short semi-axes. It is easy to understand from equation (2). While the current vector is oriented to the voltage vector, it leads to high harmonics pollution of input currents.

3.3. Proposed control system work during voltage dip

Results of the proposed approach are presented in figures 11 and 12.

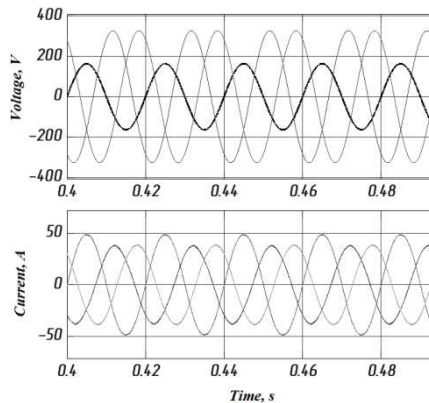


Figure 11. Unbalanced voltages and sine currents

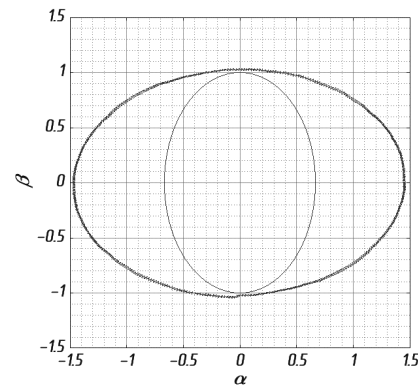


Figure 12. Hodographs of voltage and current vectors p.u.

It is seen that in the same power grid condition, currents, when using the proposed approach, are sine-waved. Hodographs confirm the proposed theory.

4. Conclusion

To obtain constant power flow and sine-waved currents, the active rectifier has to form the current vector according to the voltage vector hodograph. If this is not considered, the active rectifier becomes a source of high harmonics. The novel approach to an active rectifier control has been proposed in the paper. The method is to give a special reference to the current control loop to form sine-waved input

currents. Few additional calculations are needed to yield the desirable current vectors coordinates so it does not need lots of computing power. Computer simulation proved this technique efficiency.

5. References

- [1] Drury G, Gosbell V, Ciufo P, Smith V, Perera S and Elphick S 2015 Characteristics of power quality disturbances in Australia: voltage dips at low-voltage sites *IET Gener. Transm. Distrib.* **9** 2382–8
- [2] Besselmann T J, Cortinovis A, Van de Moortel S, Ditlefsen A M, Mercangoz M, Fretheim H, Joerg P, Lunde E, Knutsen T and Stava T O 2017 Increasing the Robustness of Large Electric Driven Compressor Systems During Voltage Dips *IEEE Trans. Ind. Appl.* **9994** 1–9
- [3] Slavgorodskii V B, Nikolaev A A, Hramshin T R, Lojkin I A and Ivekeev V S 2013 *Electrotechnical systems and complexes* **33** 253–7
- [4] Nikolaev A A, Denisevich A S, Lojkin I A and Tuhvatullin M M 2015 *Electrotechnical systems and complexes* **3** 8–14
- [5] Abramovic B N 2018 *Journal of mining institute* **229** 31–40
- [6] Shklyarskii A Y, Ustinov D A and Sychev Y A 2013 *Scientific and technical statements of St. Petersburg Polytechnic University. Natural and Engineering Sciences* **1** 93–8
- [7] Ershov S V and Jabin B A 2013 *Proceedings of Tula State University. Technical science.* **12** 62–72
- [8] Mohan N, Undeland T M, Robbins W P and Murphy K 2003 *Power electronics* ред B Zobrist (Hoboken: John Wiley)
- [9] Zarif M and Monfared M 2015 Electrical Power and Energy Systems Step-by-step design and tuning of VOC control loops for grid connected rectifiers *Int. J. Electr. POWER ENERGY Syst.* **64** 708–13
- [10] Jamma M, Barara M, Akherraz M and Enache B A 2016 Voltage oriented control of three-phase PWM rectifier using space vector modulation and input output feedback linearization theory 2016 8th International Conference on Electronics, Computers and Artificial Intelligence (ECAI) vol 30(IEEE) pp 1–8
- [11] Aboutanios E 2017 An adaptive clarke transform based estimator for the frequency of balanced and unbalanced three-phase power systems 25th Eur. Signal Process. Conf. EUSIPCO 2017 **2017–Janua** 1001–5
- [12] Park R H 1929 Abridgment of two-reaction theory of synchronous machines generalized method of analysis — Part I *J. A.I.E.E.* **48** 716–27
- [13] Emanuel A E 2010 *Power Definition and the Physical Mechanism of Power Flow* (John Wiley)
- [14] Weisstein E W 2003 *CRC Concise Encyclopedia of Mathematics* (Chapman&Hall/CRC)
- [15] Shonin O B, Kryltcov S B and Novozhilov N G 2017 The digital algorithm for fast detecting and identifying the asymmetry of voltages in three- phase electric grids of mechanical engineering facilities *MEACS2016* pp. 1–6