INFLUENCE OF VOLTAGE SAGS ON PM SYNCHRONOUS MOTOR DRIVES

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Abstract. *The aim of the paper is to analyse the effects of voltage sags on electrical drives with permanent magnet synchronous motors (PMSM). The voltage sags were simulated as results of three phases or single-phase faults, changeable in duration and magnitude. At the beginning, a PMSM with two types of rectifier were examined: six-pulse (diode) and PWM one. It is shown that the first configuration has better performance, i.e. it is very robust on voltage sags. However, capacity enlargement in DC bus contributes to smaller voltage sags immunity and bigger strain of rectifier components and network pollution.*
After that a model of a factory drive, which consists of transformer, uncontrolled induction motor (for air conditioning equipment, pumps) and a resistive load (for heater, lightning or similar) was considered. In addition to network generated voltage sags on the primary side of the transformer, extra voltage drops were detected on the secondary transformer side. It was concluded that the biggest influence on additional voltage drop has the induction motor, thought its power was smaller than the power of PMSM. It was suggested how to minimize influence of voltage sags on PMSM.
Key words: *voltage sags, PMSM, induction motor*

Introduction

A voltage sag is a reduction in rms voltage of various magnitude and duration but not the complete loss of ac power. Voltage sags are generally caused by faults on the transmission and/or distribution system. Fig 1. shows the range introduced by CBEMA (Computer Business Equipment Manufacturers Association) and ITIC (Information Technology Industry Council) for permitted values of magnitude and duration (inner side of the curves) of voltage sags and swells for normal operation of various equipment including motor drives. As an example some measured values of voltage sags occurred near Novi Sad Oil Refinery are drawn in.

Not only the sensitive industrial processes but also adjustable-speed drives could be adversely affected by voltage sags. One of the often used servo motors is permanent magnet motor. It has many good features such as very little inertia, big power density, very good dynamic performance due to it hasn't slip; maintance is simple because there are no collector and brushes. Because of that, it was interesting to study their behaviour on voltage sags.

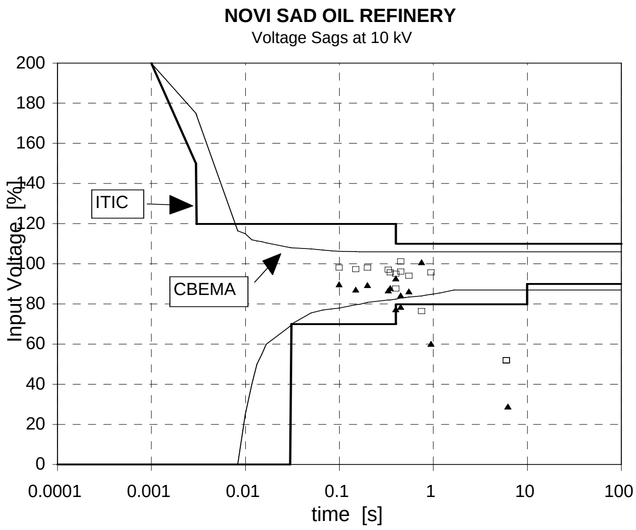


Fig. 1. CBEMA and ITIC range for permitted values of magnitude and duration of voltage sags and swells for low voltage power supply system.

In the first part of the paper only motor drive with PMSM were examined. Two types of rectifier were taken: six-pulse (diode) and PWM one. After that a model of a factory drive, which consists of transformer, uncontrolled induction motor (for air conditioning equipment, pumps) and a resistive load (for heater, lightning or similar) was considered.

System description

There is no sense to investigate PMSM connected only to power supply as it was done in [1] for AC motors. Theoretically, that configuration has two poles on imaginary axis and it is boundary stable, practically unstable. PMSM drive has standard configuration. It consists of PMSM, inverter, hysterezis current regulator and PI speed regulator. Current regulator could be also some PI type (because of switching frequency problem for inverter components) but for voltage sags analysis it doesn't matter. One configuration is fed by diode rectifier, other with PWM one. They both have LC filter. It is well known that first configuration doesn't support inverse current flow. It has brake chopper for energy dissipation produced by motor. Topology of PWM rectifier is same as topology of (PWM) inverter. Transistors obtain gate pulse in the same time when appropriate diode has to conduct. If the PMSM is in motor regime, diode will conduct. Otherwise, for PMSM in the generator regime transistor will conduct. In that way, there is no need to have brake chopper; we have energy saving also. Disadvantage is complex and expensive rectifier. The voltage sags, that were simulated as results of three phases or single-phase faults, are changeable in duration and magnitude.

In second part of the paper, there was intention to take a model, which can describe a factory drive. Besides some number of PMSMs, which actuate robot's arms, positioning parts of NC, CNC machines etc., this model takes in consideration one unregulated AC motor. It can represent air conditioning equipment, pumps, compressors. Heaters, lightning or similar consumers are modelled as three phase resistor. In order to make more reliable simulation, transformer is modelled also. The voltage sags that were simulated are the same as in the first part of paper. Power value of the transformer is 100KVA (10kV/0.4kV), AM is 15.12 KVA (11KW mechanical); it was taken 20 PMSMs with power value 20x3.3KWA=66KW. 15 KW three phase resistor gives whole power value of 96 KVA, which corresponds almost total nominal power value of transformer. Fig. 2 shows complete model.

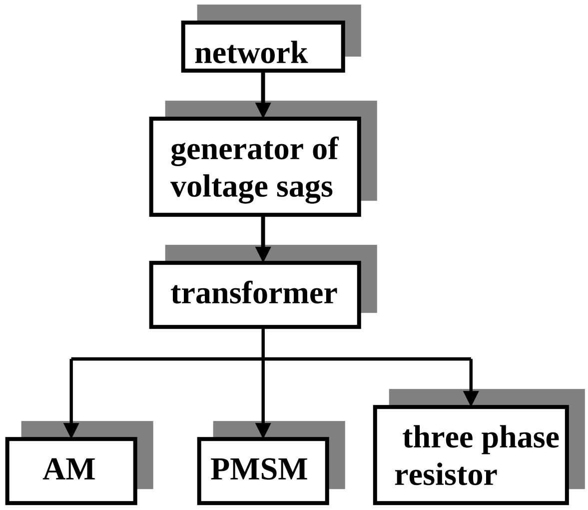


Fig. 2. Complete model of factory drive

Results of simulation

Figures 3-8 represent one phase (1phvs) or three (3phvs) voltage sags, duration of 1 second (between 0.2-1.2 sec.) for PMSM drive with diode or PWM rectifier.

Fig. 3. Speed for 1phvs, -40%, diode rec.

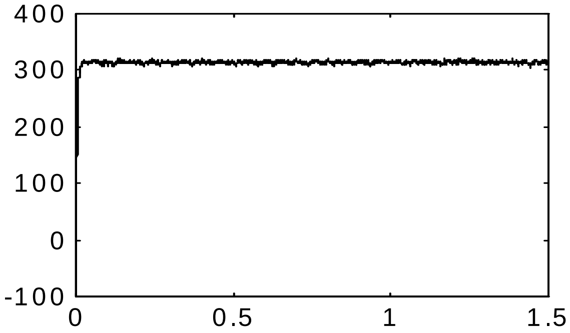


Fig. 4. Speed for 1phvs, -40%, PWM rec.

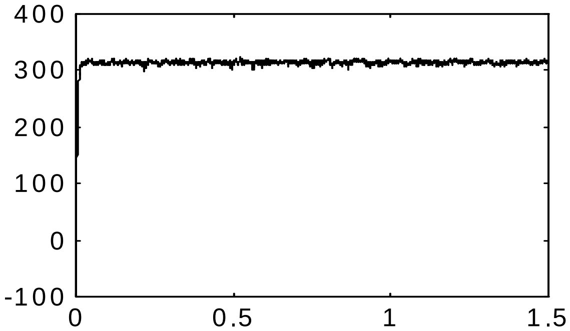


Fig. 5. Speed for 3phvs, -40%, diode rec.

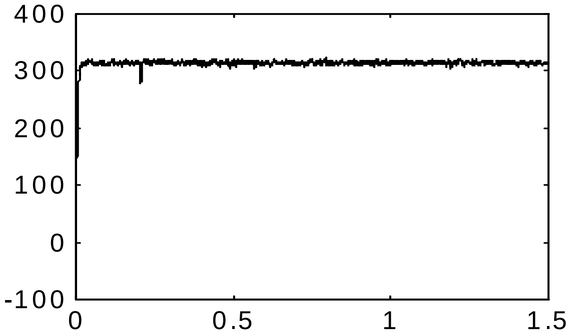


Fig. 6. Speed for 1phvs, -40%, PWM rec.

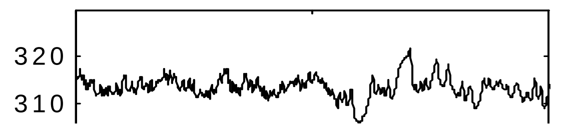


Fig. 7. Speed for 3phvs, -40%, diode rec.

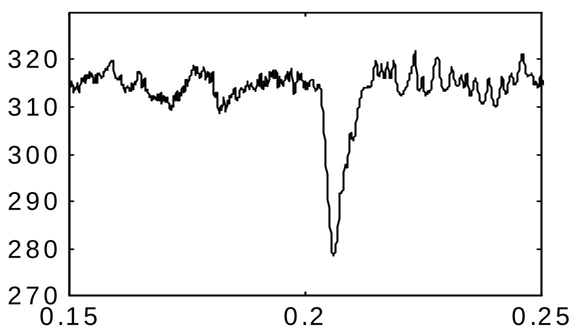
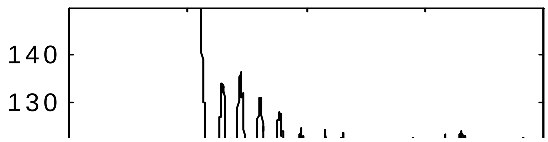


Fig. 8. Speed for 3phvs, -40%, PWM rec.

The worst case is examined: speed and load of PMSM are nominal. Thus we have the biggest electromotor force which gives minimum value between it and voltage, for the current corresponding load.

Fig. 3. and 4. show that there is no difference between diode and PWM rectifier configuration for one phase sag, magnitude of –40%. For three phase sag, magnitude of –40% we can see that PWM rectifier configuration has worse behaviour. Fig. 7. and 8. show magnified critical moment (little oscillation in speed are caused by hysterezis behaviour of current controller). It is consequence of nature of PWM rectifier. The start of voltage sag is critical. In that moment network voltage is less then capacitor voltage. Diode rectifier doesn’t allow discharging capacitor and therefore DC voltage hasn’t such drop as in PWM rectifier. It is shown in fig. 9. and 10.



. Fig. 9. Udcbus 3phvs, -40%, diode rec.

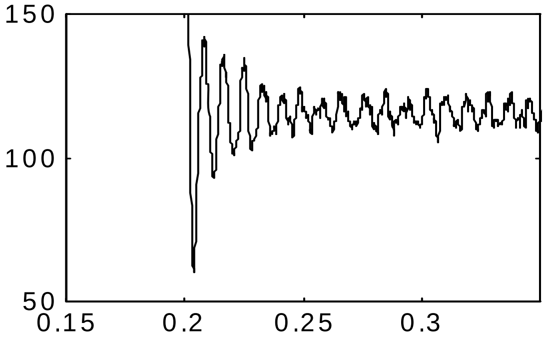


Fig. 10. Udcbus 3phvs, -40%, PWM rec.

Considering that PMSMs are mostly used in low and middle power applications (because they are expensive) it is better to take diode rectifier configuration. It is more robust on voltage sags than PWM one (that is important for servo drives). Energy saving for low and middle applications is less important. In the rest of the examination diode rectifier configuration is considered.

Fig. 11. and 12. show rotor angle theta (θ) and firing pulses for one upper transistor in inverter during three phase voltage sag, respectively.

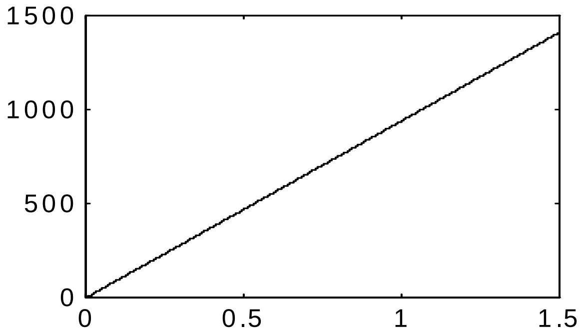


Fig. 11. θ, 3phvs, -40%, diode rec.

Fig. 12. Firing pulses for transistor, 3phvs, -40%, diode rec.

The method for sag compensation mentioned in [1], automatically exists there. We do not have to increase duty cycle when sag occurs. It is done automatically by current controller (fig. 12.). This configuration compensates voltage sags of –40% of voltage. Critical moment is the start of sag (therefore their duration is not essential).

During sag, the drive takes bigger current form network then nominal one because of the same, nominal load. After the end of sag, current peak exists, which can prolong that sag (fig. 13.)

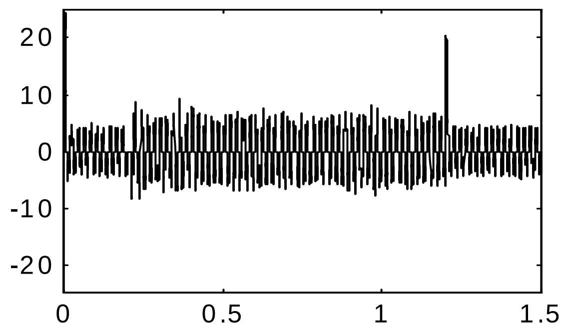


Fig.13. Network current (all three phase), 3phvs, -40%, diode rec.

That happens because of the difference between voltage of capacitor and network in the end of sag.

Three phase voltage sag magnitude of –50% affects speed drive. It is shown in fig. 14.

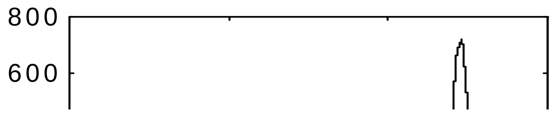


Fig. 14. Speed, 3phvs, -50%, diode rec.

Fig. 15. shows that Udc drops lower then in fig. 9.

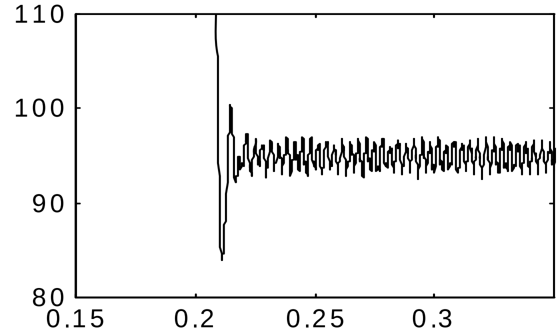


Fig. 15. Udc, 3phvs, -50%, diode rec.

Drive behaviours in case of two different capacitors in DC bus is shown in fig. 16-19. The improvement can be noticed, but only in short voltage sag (100 ms, 0.2-0.3s). It means that there is no sense to work with big value of capacitor.

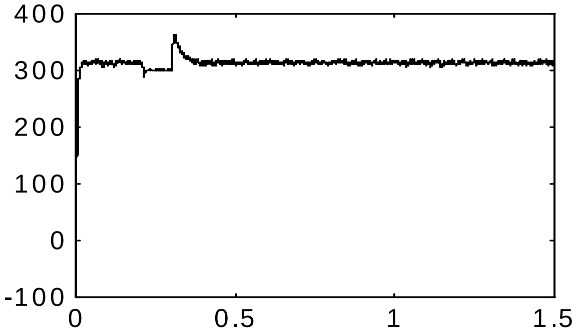


Fig. 16. Speed, 3phvs, -50%, diode rec., C=330μF

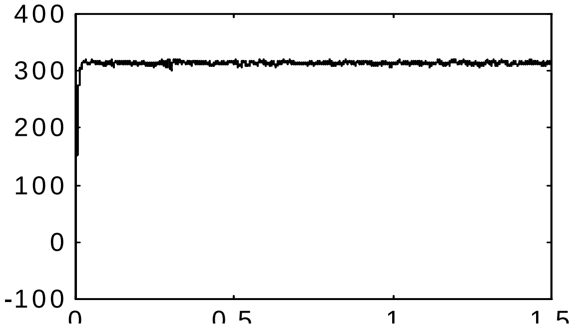


Fig. 17. Speed, 3phvs, -50%, diode rec., C=3300μF

Fig. 18. Udc, 3phvs, -50%, diode rec., C=330μF

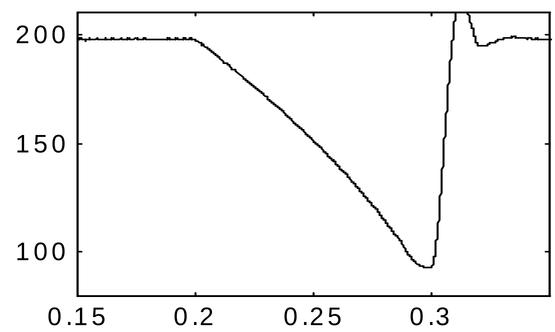


Fig. 19. Udc, 3phvs, -50%, diode rec., C=3300μF

Characteristic signals in case of fabric's drive are given at fig. 20-24.

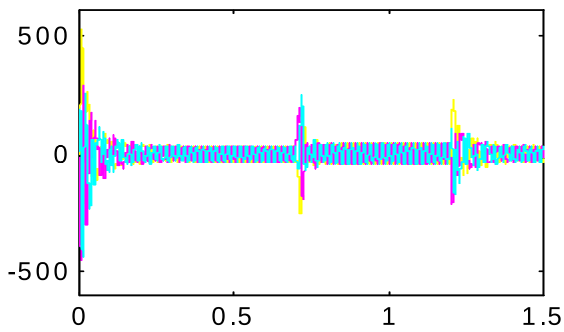


Fig. 20. Line currents, AM, 3phvs, -40%

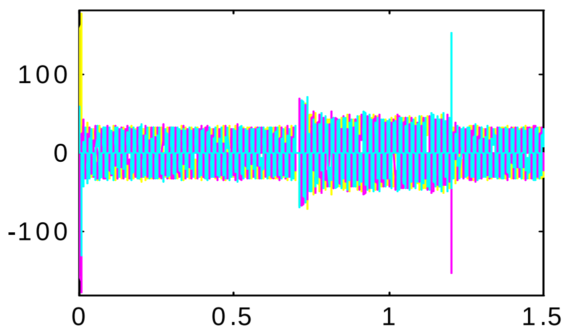


Fig. 21. Line currents, PMSM, 3phvs, -40%

Fig. 22. Line voltages, secondary side, 3phvs, -40%

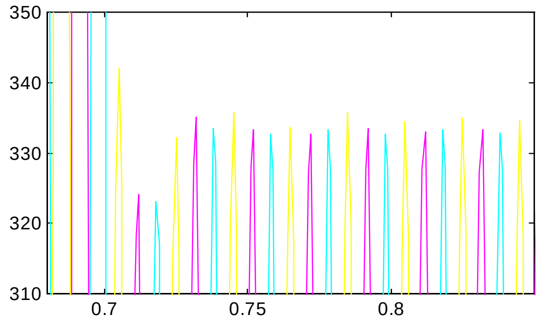


Fig. 23. Line voltages, secondary side, 3phvs, -40%

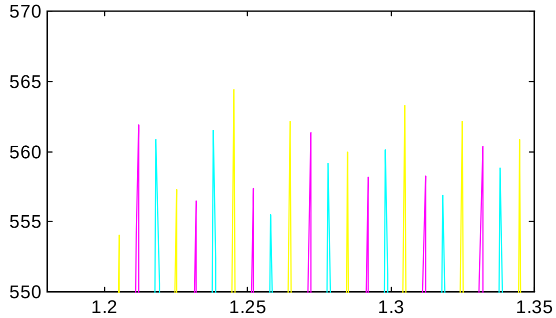


Fig. 24. Line voltages, secondary side, 3phvs, -40%

The voltage sag simulated between 0.7-1.2 sec., magnitude of –40% of nominal value. It can be seen that the asynchronous motor has bigger influence on supplementary sag then PMSM, although it has less power. It is the consequence of the nature of AM. Supplementary voltage sag is shown on fig. 23. and 24.

Conclusion

It is shown that PMSM drive with diode rectifier has better performance than drive with PWM rectifier. Diode rectifier doesn't allow discharging capacitor and therefore DC voltage doesn't have such drop as in PWM rectifier. The start of voltage sag is critical. If drive doesn't have failure during that period, it can operate well for the rest of the sag. The capacitor is increased ten times to examine how much its influence during voltage sag is positive. Drive can operate well for a bigger sag but only if it lasts for very short time.

Practically it doesn't make any sense to increase capacitor due to problems with stress of diodes and network.

Drive with active rectifier is complete solution. It reduces network pollution, boosts the DC voltage during sags and provides energy recuperation but it is more expensive.

In the case of fabric's drive induction motor has the biggest influence of additional voltage drop. Secondary side voltage oscillations at the end of voltage sag are the consequence of AM acceleration. PMSM causes bigger network pollution than AM.

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