Operational reliability of low-voltage asynchronous motors at asymmetrical supply voltage

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Abstract. Issues of operating modes of 4A series asynchronous squirrel-cage motors and AI series motors at asymmetrical supply voltage for different values of motor shaft load are considered on the basis of simulation using Matlab software package and Simulink package. In the simulation, currents in asynchronous motor phases were evaluated as a function of K_{2U} , K_Z , and based on these results, permissible operation parameters were evaluated for induction motors. The results obtained are the basis for technical solutions aimed at improving operational reliability of asynchronous motors, they will allow taking into account permissible operating parameters of asynchronous motors not only in the design, but also in operation in power supply systems of various facilities.

1 Introduction

Reliability is the most important technical and economic indicator of asynchronous motors (AM) quality which defines ability to operate reliably with unchangeable technical characteristics during a given period of time under certain operating conditions [1,2]. However, in actual electric motor operation conditions, due to various factors, there is a significant deviation from normal operating modes. The vast majority of the reason for this is poor voltage quality in the networks, in particular, asymmetry of supply voltage. Supply voltage asymmetry has a negative impact on AM, reduces operational reliability and increases risk of motor failures. Thus, service life of asynchronous motors operating under full

load is reduced by 2 times at a voltage asymmetry of 4%. When the voltage is unbalanced by 5%, available power of the motor is reduced by 5-10% [3,4].

In this paper, operation modes of 4A series squirrel-cage AM and AI series motors at asymmetrical supply voltage with different values of the motor shaft load were studied to identify AM operating modes.

Long-term trouble-free operation of AM is achieved as a result of implementation of measures aimed at maintaining technical and operational characteristics within the limits necessary for their trouble-free operation.

2 Materials and methods of the study

The study of AM operating modes can be effective if computer simulation with virtual model implemented in a visual and effective simulation tool Simulink of interactive programming environment Matlab for T-shaped induction motor equivalent circuit [5,6] are used.

Simulation scheme for studying operation modes of asynchronous squirrel-cage motor, created by means of simulation in the Matlab/Simulink environment, is shown in (Fig.1). Using developed computer model, modes of squirrel-cage AM were studied taking into account the following:

- value of the motor shaft load varied from 0 to 120 % with 20 % increments at different K_{2U} values,

- value of reverse sequence voltage asymmetry coefficient was from 0 to 5 % with 1% increments.

Study of series 4A and AI AM with a nominal motor speed $n=1500$ rpm, with a significant power spread from 5.5 kW to 200 kW, was carried out. As an example, asynchronous squirrel-cage motors of 4A series (4A132S4Y3 with $P_n = 7.5$ kW; 4A250S4Y3 with $P_n = 75$ kW; 4A315M4Y3 with $P_n = 200$ kW) and of AI series (AIR132S4 with $P_n = 7.5$ kW; AIR250S4 with $P_n = 75$ kW; AIR355M6 with $P_n = 200$ kW) were selected [7,8].

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Fig.1. Simulation scheme implemented in Matlab/Simulink environment.

On the basis of the carried-out study, for each phase of the AM under consideration, dependences of currents versus K_{2U} were plotted for various values of motor shaft loads. Main types of current change in "A" phase for series 4A AM, AI with $P_n = 7.5; 75; 200$ kW, at different values of K_{2U} and different values of the motor

shaft load are shown in (Fig.2-4). It should be noted that the control value of permissible overload current equal to 1.1 of the nominal current is taken into account when performing the studies [9,10].

Fig.2. Curve of current in phase "A" AM series 4A, AI with $P_n = 7.5$ kW from K_{2U} under different permanent load factors.

Fig.3. Curve of current in phase “A” AM series 4A, AI with $P_n = 75$ kW from K_{2U} under different permanent load factors.

Fig.4. Curve of current in phase “A” AM series 4A, AI with $P_n = 200$ kW from K_{2U} under different permanent load factors.

3 Results of the study and discussion

On the basis of the results obtained in the course of computer simulation and using linear approximation of the data, analytical dependence of the AM current in the most loaded phase depending on the factors - reverse sequence voltage asymmetry coefficient (K_{2U}), load factor (K_z), type of series and the electric motor power - was derived.

The AM current dependence was defined by formula:

– for 4A series motor:

$$I \% \text{ of } I_{\text{nom}} = ((-0.0002P + 0.163) K_{2U} + (0.8126 K_z + 0.081)) * 100, \%$$

– for AI series motor:

$$I \% \text{ of } I_{\text{nom}} = ((-0.0003P + 0.1535) K_{2U} + (0.8126 K_z + 0.081)) * 100, \%$$

The conducted study allowed establishing the following regularities:

1) at supply voltage asymmetry, following indicators influence permissible AM parameters: power, load factor (K_z) and coefficient of negative sequence voltage asymmetry (K_{2U}),

2) permissible AM operation parameters (at normal AM operation mode) are identified based on overload capacity.

Table 1. Permissible values of load factor AM series 4A, AI at different values K_{2U} .

Permissible K_z AM series 4A, AI at different K_{2U}	Motor power capacity, kW		
	7.5	75	200
K_z 4A, of $K_{2U} = 0\%$	110%	110%	110%
K_z AI, of $K_{2U} = 0\%$	110%	110%	110%
K_z 4A, of $K_{2U} = 1\%$	90%	92%	95%
K_z AI, of $K_{2U} = 1\%$	91%	93%	96%
K_z 4A, of $K_{2U} = 2\%$	70%	74%	80%
K_z AI, of $K_{2U} = 2\%$	73%	76%	82%
K_z 4A, of $K_{2U} = 3\%$	50%	55%	65%
K_z AI, of $K_{2U} = 3\%$	54%	59%	68%
K_z 4A, of $K_{2U} = 4\%$	31%	37%	49%
K_z AI, of $K_{2U} = 4\%$	35%	42%	54%
K_z 4A, of $K_{2U} = 5\%$	11%	19%	34%
K_z AI, of $K_{2U} = 5\%$	16%	25%	40%

3) the permissible value of K_{2U} is determined, when the engine is fully loaded

Table 2. Permissible values of coefficient asymmetry on the reverse sequence of AM series 4A, AI.

Valid K_{2U} AM series 4A, AI	Motor power capacity, kW		
	7.5	75	200
K_{2U} 4A	1.28	1.39	1.68
K_{2U} AI	1.36	1.58	2.21

Thus, permissible values of K_{2U} are different not only for different AM series, but they also vary within the motor series, and they directly dependent on the motor power.

In accordance with standards GOST 32144–2013, permissible AM operating parameters are:

a) at K_{2U} from 0% to 2%, range of normal operating modes of 4A series AM is K_z from 0 % to 70%, range of normal operating modes of AI series AM is K_z from 0 % to 80%,

b) at K_{2U} from 2% to 4%, range of normal operating modes of 4A series AM is K_z from 0 % to 31%, the range of normal operating modes of AI series AM is K_z from 0 % to 35%.

In the case of long-term operation, normal AM operation at $K_{2U} = 2\%$ is possible with reduced load:

- for 4A series motor with $P_n = 7.5$ kW - to 70%, for AI series motor with $P_n = 7.5$ kW - to 73%,
- for 4A series motor with $P_n = 75$ kW - to 74%, for AI series motor with $P_n = 75$ kW - to 77%,
- for 4A series motor with $P_n = 200$ kW - to 80%, for AI series motor with $P_n = 200$ kW - to 82%.

4) permissible K_{2U} range (in the case of AM normal operation) at full load of the motor is defined as follows:

- for 4A series motor with $P_n = 7.5$ kW - allowable K_{2U} range is from 0 to 1.28%, for AI series motor with $P_n = 7.5$ kW - allowable K_{2U} range is from 0 to 1.36%,
- for 4A series motor with $P_n = 75$ kW - allowable K_{2U} range is from 0 to 1.39%, for AI series motor with $P_n = 75$ kW - allowable K_{2U} range is from 0 to 1.58%,
- for 4A series motor with $P_n = 200$ kW - allowable K_{2U} range is from 0 to 1.68%, for AI series motor with $P_n = 200$ kW - allowable K_{2U} range is from 0 to 2.21%.

As a result of the study on influence of main factors on AM operation mode, it should be noted:

1) regulation of K_{2U} should be performed based on the permissible operating modes of motors and their commercially available models. It was found that, at long-term or repetitive voltage asymmetry, technical balancing means with output asymmetry of not more than 1.3% should be provided for AM power supply sources even if K_{2U} value complies with requirements of GOST 32144 – 2013 [11],

2) necessity of optimal solution to change AM load or application of input technical balancing means in

power supply system is defined primarily by following factors: technical and economic analysis of the solution feasibility; nature of asymmetry in the network; features of the production process in the enterprise. Based on the obtained data on permissible K_{2U} value, technical balancing means should be applied for AM when $K_{2U} = 1.3\%$ is reached; if K_{2U} exceeds this value, it is necessary to reduce the AM load. So, for example for 4A series AM with $P_n = 7.5$ kW at $K_{2U} = 3\%$, it is necessary to reduce the load by 50%; for 4A series AM with $P_n = 200$ kW at $K_{2U} = 3\%$ - by 35%. When the motor load is reduced, range of normal operating mode is doubled. If the technological process of the enterprise and drive mechanisms connected to the AM care able reduce the load, this method can be more cost-effective in the short production term than installation of technical balancing means or purchasing of more powerful AM,

3) in the AM operating conditions, when power supply network containing electric motor equipment is designing, it is necessary to take into account influence of permissible K_{2U} , K_z values. This will increase reliability and efficiency of asynchronous motors and power supply systems in general.

Conclusion

By means of computer simulation experiments, using Matlab software package and Simulink package, permissible operating parameters of asynchronous motors were defined. Quantitative evaluation of main factors influencing AM operation mode is shown with examples. This study results can be used to solve problems of power quality management optimization at enterprises.

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