New IE2/IE3/IE4 energy-saving motors – influence on coordination of fuses

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Introduction

Saving energy has become a general and global demand of all nations worldwide. Beside changes in car drives and electrical lighting the new generations of energy-saving motors are a significant part of the worldwide energy-saving potential. In many countries so-called Minimum Efficiency Performance Standards (MEPS) have been introduced. Beside the interesting facts of the worldwide roll-out of the new motor generations IEC2 up to IEC4 we are much more interested in the changes of electrical behaviour and the consequences of electrical components of the motor circuit. Very interesting details concerning switches and motor starters had been presented at the conference ICEC 2014; The 27th International Conference on Electrical Contacts [1]. The published documents give further detailed information about the changes of motor characteristics, too.

Legislation and Standards

1_EU Commission Regulation (EC) No. 640/2009

The introduction of the new motor generations IEC2, IEC3 and IEC4 in the different worldwide markets has been started or is scheduled within the next couple of years. For Europe the EU Commission Regulation (EC) No. 640/2009 "Ecodesign Requirements for Electric Motors" had been published. Article 3 "Ecodesign requirements" shows following timeline:

"1. from 16 June 2011, motors shall not be less efficient than the IE2 efficiency level, as defined in Annex I, point 1

2. from 1 January 2015: (i) motors with a rated output of 7,5-375 kW shall not be less efficient than the IE3 efficiency level, as defined in Annex I, point 1, or meet the IE2 efficiency level, as defined in Annex I, point 1, and be equipped with a variable speed drive.

3. from 1 January 2017: (i) all motors with a rated output of 0,75-375 kW shall not be less efficient than the IE3 efficiency level, as defined in Annex I, point 1, or meet the IE2 efficiency level, as defined in Annex I, point 1, and be equipped with a variable speed drive."

Some other countries outside Europe may follow this timeline.

2_Motor Standard IEC 60034
Different standards of the IEC 60034 range “Rotating electrical machines” such as IEC 60034-30-1 “Efficiency classes of single-speed three-phase cage induction motors” and IEC 60034-12 “Starting performance of single-speed three-phase cage induction motors” determine the performance and mechanical and electrical data of the different motor generations. Unfortunately part 12 is still under consideration – therefore I am not able to give more details now. The current standard still does not show the changing data overall, but there is foreseen to adopt the “table 2, maximum values of locked rotor apparent power …” which defines this important value as the ratio of S_l/P_n. These values will increase while motor rated currents will decrease.

S_l … electrical locked rotor apparent power

P_n … mechanical motor power

3_Switchgear standard IEC 60947
Switchgear such as motor-starters in accordance to IEC 60947-4-1 “Contactors and motor-starters – Electromechanical Contactors and motor-starters” are concerned by the changing motor data. Therefore national and international standardization committees and their taskforces work on adaption of switchgear standards. For e.g. new utilization categories had been defined. To perform the harder conditions while operation or during the inrush-phase re-design or re-testing of the contacts or the contact system may be necessary. Additionally the higher inrush-currents and/or higher locked rotor currents may require re-adjustment of trip-levels of trip units.

More details about this can be learned from [1] the script of 27. ICEC (International Conference on Electrical Contacts) in Dresden with following title: “Increased requirements on the switching behaviour of industrial switchgear caused by new high-efficiency motors”.

4_Fuse standards
Fuses in accordance to IEC 60269 range may be concerned too, but the impact of new motor data onto the fuses seems to be less than the impact onto the switchgear.

Current IEC 60269 standards don’t define special features and tests related to new generations of motors and its data changes. The related characteristics of the fuses given by the standards are time-current-zones and the fusing and non-fusing current which are well-known as overload gates. The best suitable fuses for motor protection are IEC fuses with utilization category aM or UL fuses of different classes with time-delay characteristic. Generally, and especially general purpose IEC fuses with utilization category gG are used, the applicant has to be care that the time/current curves of the fuse and of the locked rotor current provide a safety distance to each other. This situation is not new but becomes more critical than in the past.

Behaviour of high efficient motors

In order to achieve the given MEPS, motor manufacturers have improved and partly redesigned their motors. The most common changes are: [1]

- *lower stator resistance, in most cases due to increased slot space factor*
- *lower rotor resistance, by using copper instead of aluminium at least partly*
- *improved electric sheet steel to improve magnetization and to lower eddy currents*
- *longer rotor design or more generally using more active magnet material*
- *reduced air gap between stator and rotor to lower magnetic resistance*
- *improvements in bearings and in cooling to reduce side losses*

As a general rule, these new motor generations feature the following changes (IE3 compared to IE1): [1]

- *a lower nominal current I_n of about 3-5 % on average, smaller motors slightly more, bigger motors a shade less*
- *power factors at full load do not shift significantly towards any direction*
- *the starting current ratio I_S/I_n increases of up to 30% for small motors (<3 kW), and at least 10 to 20% for medium size motors, but less than 3% for motors from 75 kW and over*
  Later note of the author of [1]: "These numbers are a bit smaller."
- *the ramp-up time is marginally shorter*
- *the temperature rise is about 10 – 15 K lower.*

This substantial increase of the starting current ratio I_S/I_n can be taken from Fig. 3, which is +11% for IE2 with respect to IE1 and about 18% for IE3. IE4 is even higher at 24%, but there are only a few data available, especially for smaller motors. This increase is much lower for motors with higher power, as already mentioned above. [1]

However, in general, bigger motors tend to have higher ratios, while the starting ratio of small and medium motors is very diverse. Consequently, a ratio of 8.5 to 9.5 has to be considered for the most IE3 or IE4 motors. [1]

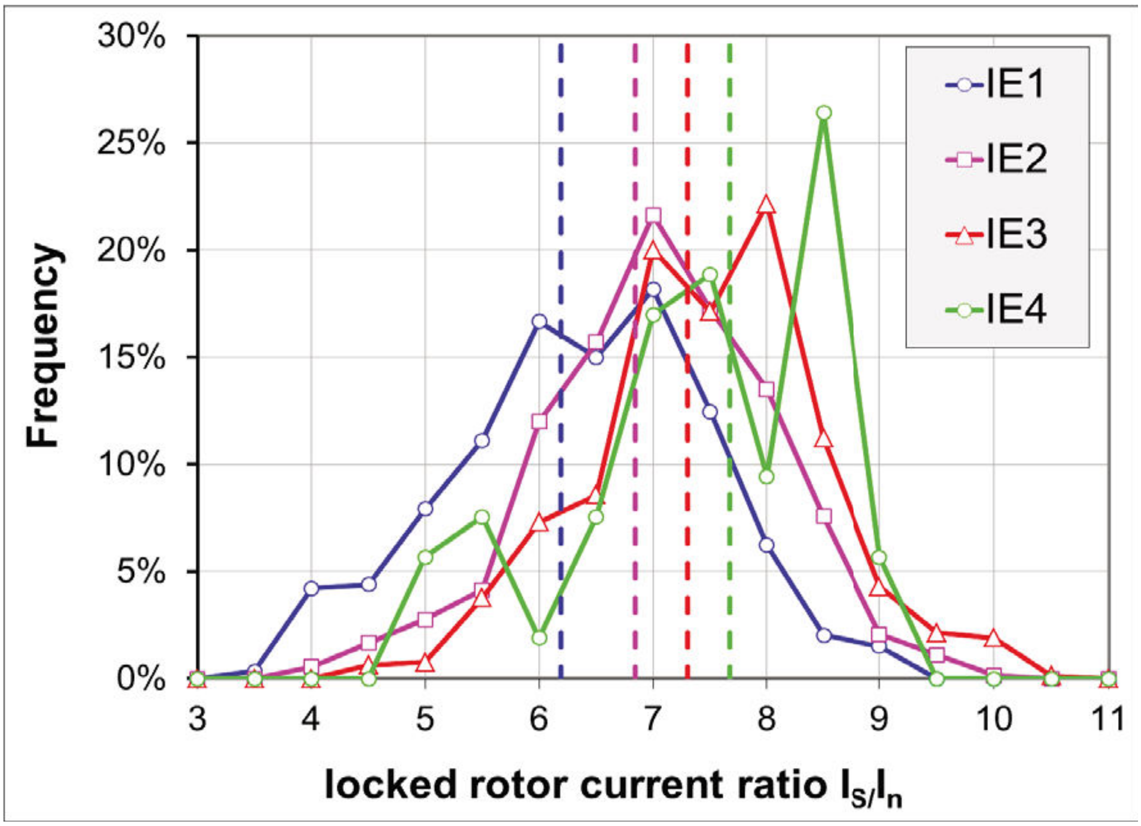


Fig.1: *[…] Frequency distribution of the locked rotor current ratio I_S/I_n (400 V, 50 Hz, 2-6 pole pairs, 0.75-55 kW; catalogue data; IE1 #594 IE2 #726 IE3 #794 IE4 #53) [1]*

It has to be mentioned that the starting current ratio I_S/I_n also depends on the motor temperature and the real value of the supply voltage. Normally this value is determined under steady-state conditions with a fixed or a very slow running rotor (<3 rpm). Unfortunately the motor standard IEC 60034 does not specify how to determine this value. However, a tolerance of 20% is permitted, a bandwidth that is actually used by the manufacturers. The requirements imposed on the make capacity of contactors or circuit breakers result from the dynamic superposition of four different factors, namely the nominal current of the motor I_n, the starting current ratio I_S/I_n, superimposed transient currents due to instabilities in system behaviour at the beginning of the ramp-up and due to inrush current I_r in the very beginning. [1], […]

Influence on coordination of fuses

These data described in chapter 3 are not sufficient for evaluation of the fuse operation - we need comparable data of the motor starting process. Following figures 2, 3 and 4 show the measures of an IE2 and an IE4 7,5 kW motor tested with different loads 30Nm and 50Nm and rotational mass moments of inertia 0,1kgm² and 0,2kgm².

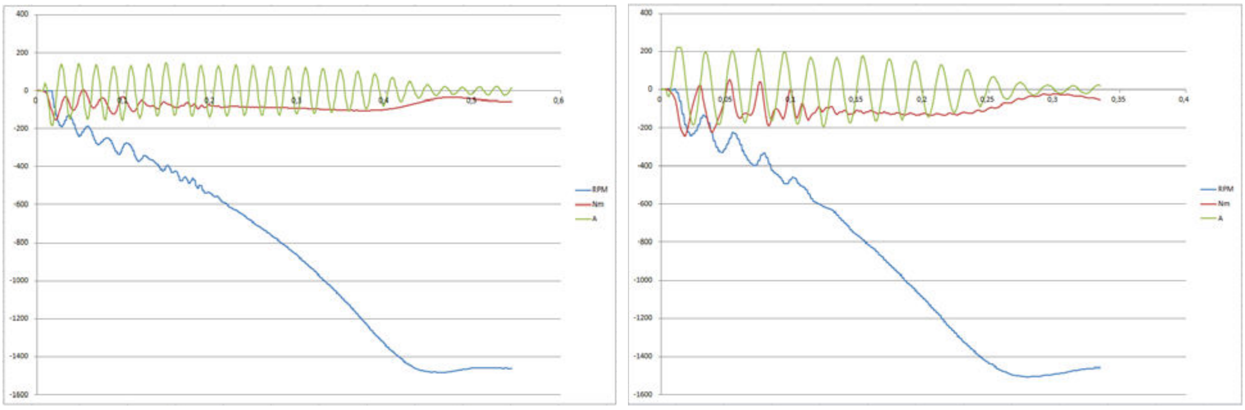


Fig. 2 IE2 vs. IE4 motor start at load 50Nm 0,1kgm² constant

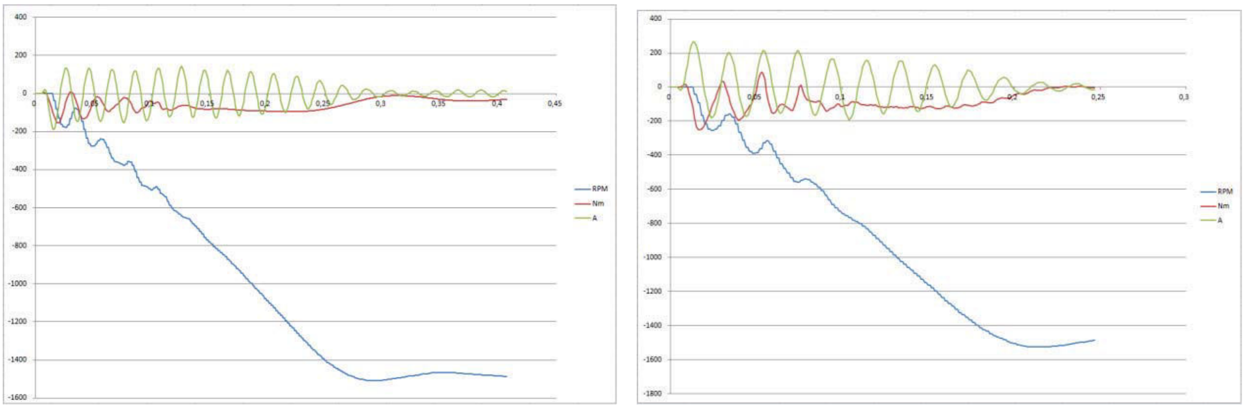


Fig. 3 IE2 vs. IE4 motor start at load 30Nm 0,1kgm²

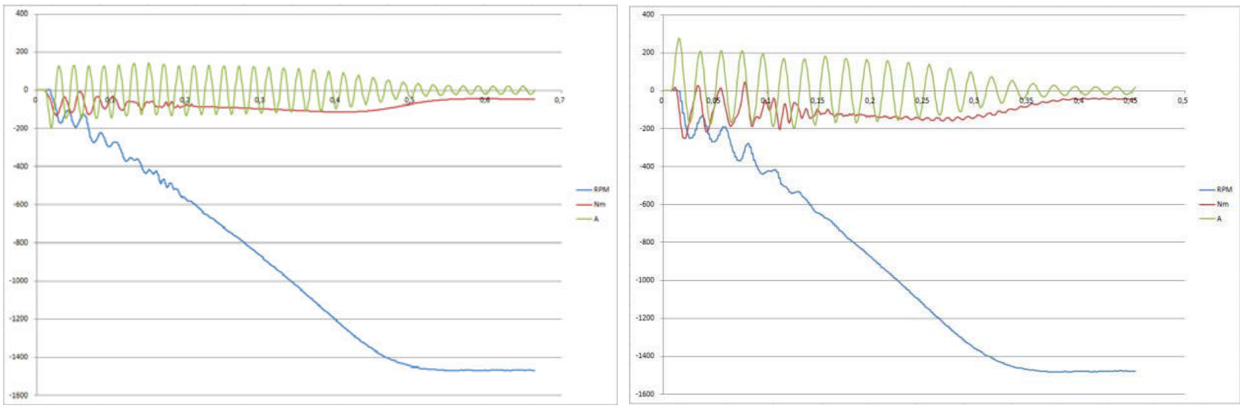


Fig. 4 IE2 vs. IE4 motor start at load 50Nm 0,2kgm²

The figures above provide general information but insufficient for evaluation of fuse coordination. Based on the measured data behind these curves we had been able to calculate energy values of the motor start procedures described as I²t.

Note, this example and the next figures don't show maximum or average values of all motors. Not contrary to the changes of motor data described in chapter 3 it demonstrates a tendency of relevant data depending on the motor load.

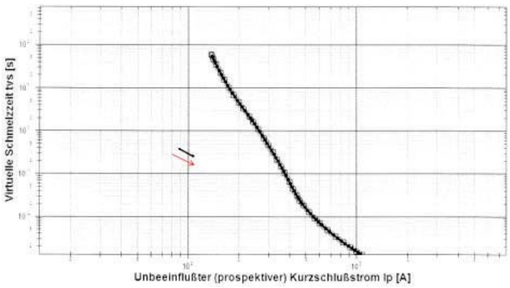
The following table 1 summarizes and simplifies the data of the figures above. It shows the changes of motor-start-values of 7,5 kW motors of IE2 and IE4 generation:

- the locked rotor currents I_S increases up to 33%.
- the relevant time shortens to -40%.
- the I^2t-values increases up to 31%.

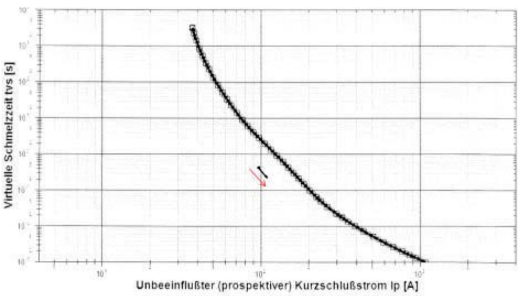
load	measures	IE2 motor	IE4 motor	delta
50Nm 0,1kgm² constant	I_s	89 A	113 A	+27%
	t_s	0,43 s	0,28 s	-40%
	I^2t	3410 A²s	3583 A²s	+5%
30Nm 0,1kgm²	I_s	85 A	108 A	+27%
	t_s	0,27 s	0,22 s	-19%
	I^2t	1949 A²s	2556 A²s	+31%
50Nm 0,2kgm²	I_s	85 A	113 A	+33%
	t_s	0,49 s	0,35 s	-29%
	I^2t	3525 A²s	4446 A²s	+26%

Table 1 comparison of IE2 and IE4 7,5 kW motor starts at different loads

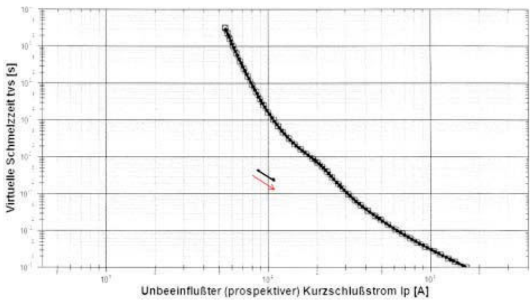
Transferring the red colored data from the table above to the time-current-zones of the IEC 60269 fuses we can see the effect. Figure 5 shows the positions of the both points of I_s, t_s (connected by a trend-line) to the time-current-zones. The arrow shows the move from the IE2 to the IE4 motor. The point of the IE4 motor has moved to a closer position.



25A aM



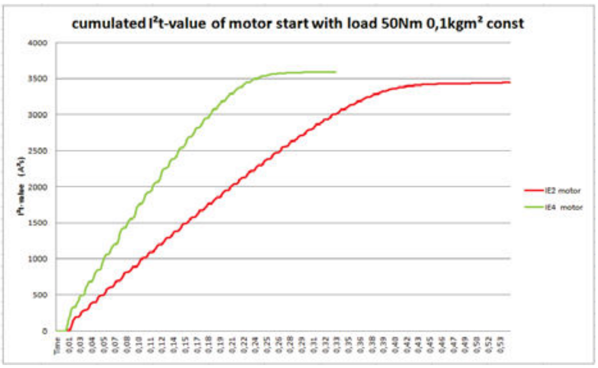
25A gG



35A gG

Fig. 5   time-current-zones of aM and gG fuses in relation to motor start data

The graphs of figure 6 shows the run of the energy values I²t of the IE2 and IE4 7,5 kW motor starts.



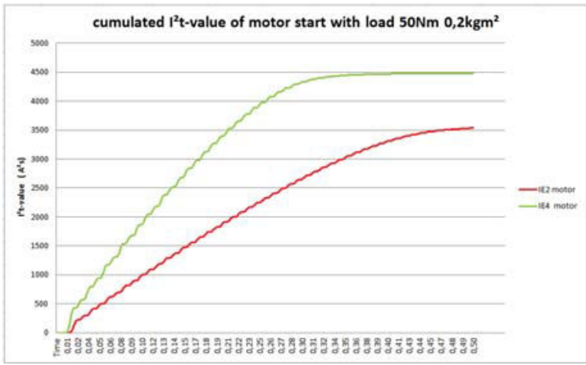


Fig. 6   run of the energy values I²t of IE2 and IE4 7,5 kW motor starts at different loads

The graphs of figure 7 shows the run of the energy values I²t of the IE2 and IE4 7,5 kW motor starts too, completed by the data of selected fuses. The result is similar to figure 5: the distance between fuse curves and the motor curves changed - the IE4 motor moved to a closer position.

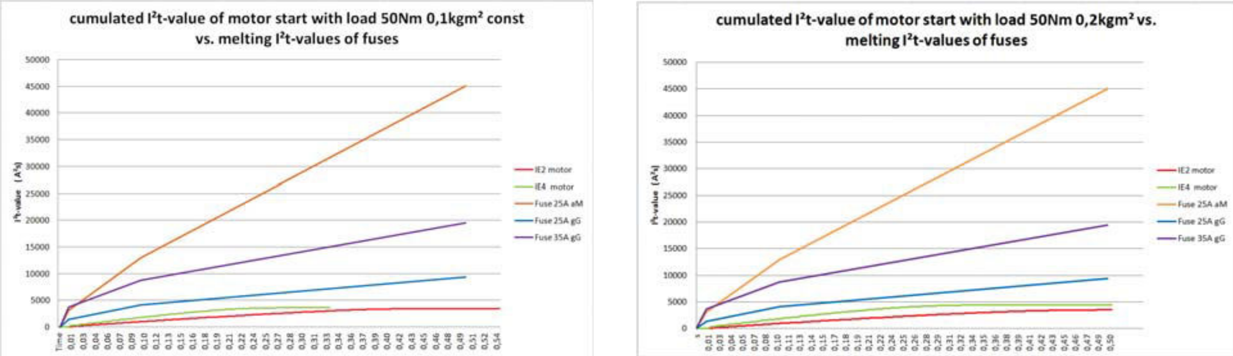


Fig. 7 run of the energy values I²t of IE2 and IE4 7,5 kW motor starts in relation to the I²t-values of aM and gG fuses

To summarize the results of the figures 5 to 7 we can state that the I²t-values of the IEC4 motor start increase depending on the load situation. Following the recommendation to apply aM fuses the changes may be negligible - while using gG fuses it may become critical.

Finally not to forget the inrush current: the look at the curves (figures 2, 3, 4) demonstrates that the peak inrush current increases too, but this value is less important for consideration of fuse operation than for load-break switches. Furthermore, the shown values cannot be compared due to different making-angles occurred at these tests. The making-angle influences the height of the 1st peak significantly. Therefore, this paper doesn't consider the inrush peak more deeply.

Unfortunately, today we are not able to show determined values of all motors worldwide and therefore these data have to be seen as examples. But these examples show a clear tendency. The author of this paper is not able to give proofed information how far these values are representative. Furthermore it must be pointed out that there is a wide bandwidth of the motor data caused by a wide range of modifications influencing mechanical and electrical behaviour of the motors described in the chapters 2.2 and 3 above.

All members of the fuse branch are in favor of the decision not to change any fuse-characteristic in the relevant fuse standards. In consequence of the changing motor data it may be necessary to re-adjust the tables which coordinate motors, fuses, overload-relays and cross-sections of cables.

Summary
High-efficiency motors are playing an important role in saving energy in industrial applications. However, their different electrical behaviour has to be considered in the future. In the case of contactors, it is certainly possible to use bigger frame sizes to handle the increased starting currents. However, this entails larger installation space and cost disadvantages. It should be the ambition of the switchgear manufacturer to overcome these difficulties by a higher make and break capacity alongside an increased current carrying capacity […]. [1]
Concerning the fuses, planners and applicants are asked to be care of the lower nominal currents of the new motors versus the higher locked rotor currents and the higher energy values (I^2t-values) of the motor starting process. Otherwise undesirable interruptions caused by blowing fuses may occur. Coordination tables for choosing the right combination of overload device and suitable fuse-rating for protection of different motor generations may need consideration or rework. All members of the fuse-community are asked to support this process. A wrong coordination may increase the failure rate in the networks. This may be seen as a gap of the fuse-characteristic or a failure of the fuse. It should be our all interest to avoid such a misinterpretation. Under consideration of the wide range of influences such as the number of different motors and their design changes, the wide bandwidth of motor data, the influence of several motor starting procedures and finally differing load situations it seems so that we don't need the ONE SOLUTION but a few small adjustments.

[…] On the other hand, the motor manufacturers and also the related standardization for motors should ensure that locked rotor currents and inrush currents remain at a reasonable level in order to ensure compatibility with existing installations and to protect the electrical supply against considerable voltage dips. [1]

References

- [1] Kraetzschmar A., Feil W., Herbst R., Klann H., Viehauser T., Increased requirements on the switching behaviour of industrial switchgear caused by new high-efficiency motors, ICEC 2014; The 27th International Conference on Electrical Contacts; Proceedings of, published by VDE, Print ISBN: 978-3-8007-3624-9

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