

Investigation of an Active System of Reactive Power Compensation for Induction Motors

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Introduction

Induction motors consume active and reactive power from network [1]. This fact causes consumed current lagging in phase from voltage. Consumed reactive power causes extra power losses in motor and in network. Therefore, it is necessary to realize reactive power compensation and research behavior of such system in different conditions. Usually such compensation is realized with capacitors switched in parallel to load. Unfortunately capacity can't be changed smoothly. In this case possibility for smooth change of reactive power must be considered.

Realization scheme with capacitor and regulated reactor block

One of schemes for such requirements is shown in Fig.1. Compensation capacitors C are switched parallel to induction motor. For operative compensation and to provide changes of compensation power accordingly to motor current and reactive power, regulated reactors L are used that together with unregulated capacitors can change balance of reactive power smooth.

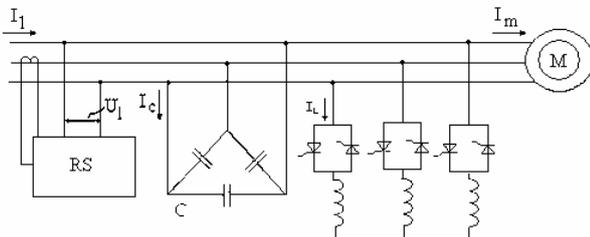


Fig. 1. Realization scheme for operative realization of reactive power

In dependence on necessity the common capacitive reactive power is controlled by regulation system (RS), affecting on thyristors in reactor circuit. RS can measure line voltage (for example U_{CA}) and phase B current. Reactive power appears, when bias between U_{CA} and I_B vectors is not 90° . In this case it is necessary to provide such equivalent capacity in parallel to load and accordingly

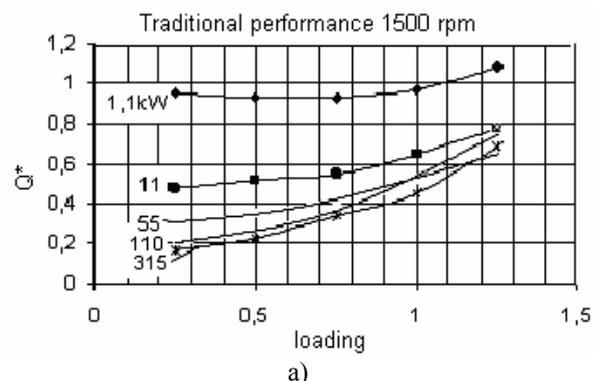
such total current ($I_c - I_L$), which can compensate this bias angle between motor current I_m and voltage. Compensation system total power $Q_S = Q_C - Q_L$ in regulation process must be equal with consumed reactive power Q_m of motor, that is, $Q_S = Q_m$. This equality ($Q_S = Q_m$) is variable and dependent on load and operating regime.

Induction motor as consumer of reactive power

It is hard to evaluate theoretically consumed reactive power of induction motor [1]. However, applying standard technical data of motor it is possible to determine consumed reactive power at different loads and different motor types and powers. For example in this work induction motor A4 data is used [2].

When processing motor A4 data it is possible to get relative connection of consumption of reactive power for realization modes and power at different loads of such motor, that is, $Q^* = f(P_2^*)$, where $Q^* = Q/P_N$, $P_2^* = P_2/P_N$, P_N is nominal power of the drive, P_2 – rated power of the load. Relative load of motor A4, P_2^* is given within 0.25 till 1.25.

Such curves for motor with rotating frequency 1500 rpm are presented in Fig. 2. As we can see, if loading grows up then consumed reactive power increases. Besides if the power of the motor is bigger, then growths of reactive power are bigger, however self consumption of reactive power of the motor is lower.



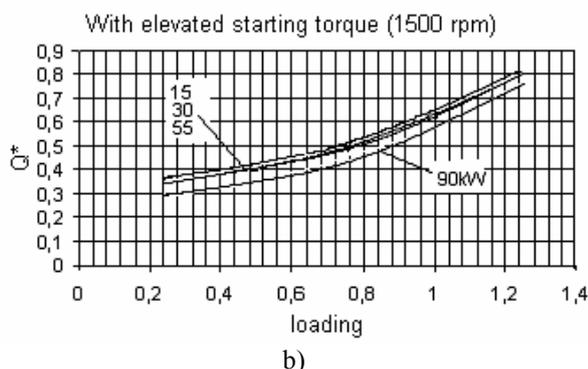


Fig. 2. Changes of relative reactive power Q^* in different power motors dependent on load: a) traditional performance, b) with elevated starting torque

To generalize acquired connections, normalized impact factor (rpm, load factor, rated power) statistical evaluation was made. The smallest impact factor as normalized with value -1 , but the biggest one with normalized value $+1$.

Consequently $P_{2min}^* = 0,25$ is with normalized value -1 , $P_{2max}^* = 1,25$ with value $+1$; respectively $P_{Nmin} = 1,1$ kW is -1 , $P_{Nmax} = 315$ kW is $+1$; $n_{smin} = 750$ rpm is -1 , $n_{smax} = 3000$ rpm is $+1$. Now in conventional motor performance relative consumed reactive power can be expressed with normalized factors:

$$Q^* = 0,844 - 0,27n_s^* - 0,327P_N^* + 0,21P_{2n}^* \quad (1)$$

Average quadratic deviation of this expression is $\sigma = 0,06$.

Normalized parameters are formulized as:

$$\begin{aligned} P_{2n}^* &= -1,5 + 2P_2^* \\ n_s^* &= -1,67 + 0,00089n_s \\ P_N^* &= -1,007 + 0,00637P_N \end{aligned} \quad (2)$$

Obviously that if n_s is bigger relative consumed reactive power is smaller. Similarly, if rated power grows, relative consumed reactive power decreases. But if load grows then relative consumed reactive power grows. At the middle parameters (all normalized factors are zero) relative consumed reactive power is $0,844$.

Range of nominal power of each synchronous speed of drive with elevated torque are very different (Fig. 3).

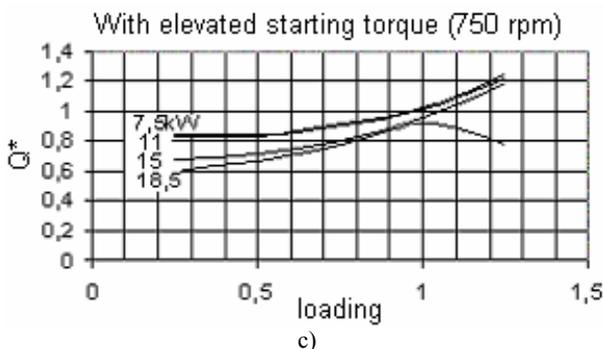
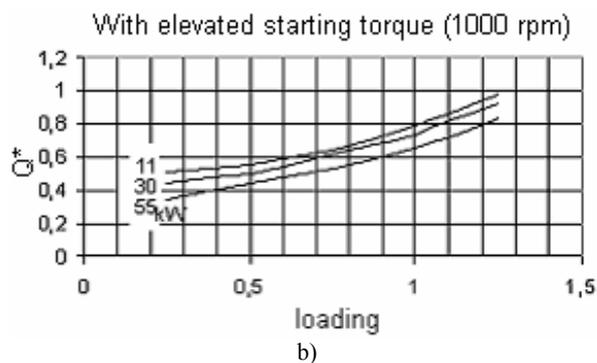
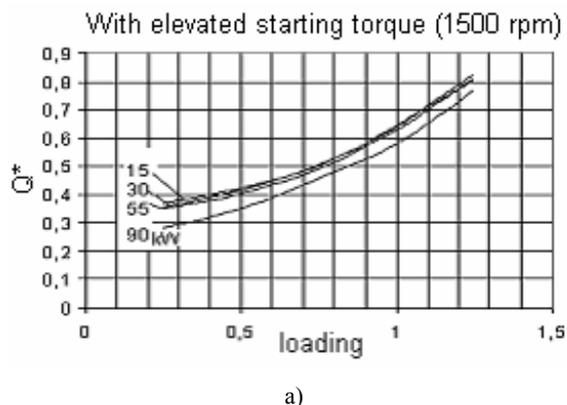


Fig. 3. Relative consumed power dependent on load for motors with elevated starting torque

Also in this case relative consumed reactive power grows if load grows, but this growth is not so big as before. In addition dependence on rated power is smaller, but if n_s grows, then consumed reactive power decreases.

In starting process from the data [2], relative consumed reactive power Q^* of the motor reaches the values $8 \dots 9$, i.e. consumed reactive power is $8 \dots 9$ times bigger than rated. That significantly complicates the realization of compensation.

Choice of parameters of the compensator

Power of the capacitor must be chosen from maximal consumed reactive power of the drive in the rated operation area. As it was mentioned, the biggest consumed reactive power is at the starting of the motor [1] that several times exceed rated power of the motor. It would be unprofitable to choose compensation system for starting regime because dimensions of device would grow as also costs. It would be rational to make compensating device for regimes between no-load operation and rated load. In this case capacitor $Q_C^* = Q_C/P_N$ must be equal to relative consumed reactive power at the load P_N . Considering expression (2), in this case normalized load factor is $P_{2n}^* = 0,5$ and then relative power of the capacitor is calculated from the expression

$$Q_C^* = 0,949 - 0,27n_s^* - 0,327P_N^* \quad (3)$$

Accordingly to this expression in Fig. 4 is given curves $Q_C^* = f(P_N^*)$.

In Fig. 4 there are shown the changes of Q_C^* dependent on P_N^* .

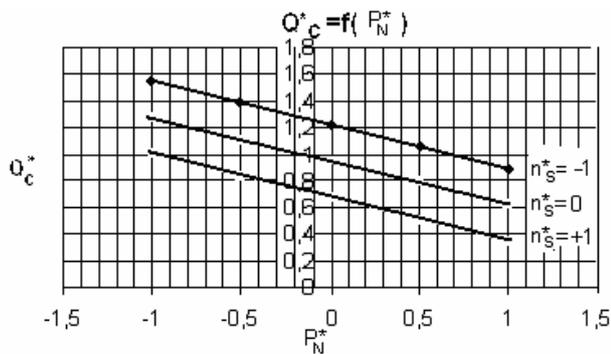


Fig. 4. Changes of relative capacitive reactive power dependent on P_N at different types of motors with $n_s=1500$ 1/min

As it can be seen capacitors with bigger reactive power are necessary for motors with smaller rated revolutions. When rated power is increased, relative capacitive reactive power decreases.

Inductive reactive power of the system must be equal to chosen value of capacitive reactive power of capacitor and difference $Q_L=Q_C-Q_{min}$ in operation diapason of rated minimal consumed reactive power of motor. Considering (1) and (3), $Q_L^*=0,315$. To compare Q_L^* and Q_C^* with calculated, in Table 1 from diagrams and from gained expressions determined Q_L^* and Q_C^* are given.

As we can see from table, when bigger motor power is used the calculations from expressions are computed with good accuracy. At smallest powers the deviations are relatively big. On average the quadratic deviation of relative reactive power of capacitor is 0,096, but for relative reactive power of reactor is 0,064.

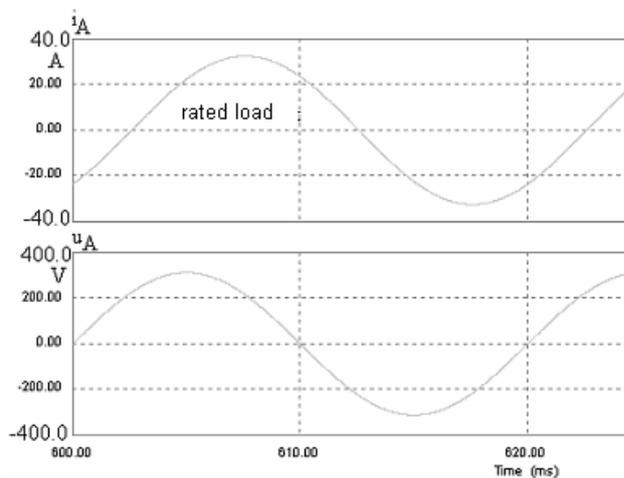
Table 1. Comparison of fixed with calculated: Q_L^* and Q_C^*

n_s^*	P_N^*	Q_C^* (from curves)	Q_C^* (calculated)	Q_L^* (from curves)	Q_L^* (calculated)
-1	-1	1,54	1,546	0,11	0,315
-1	+1	0,66	0,892	0,31	0,315
+1	-1	0,73	1,006	0,16	0,315
+1	+1	0,49	0,352	0,33	0,315

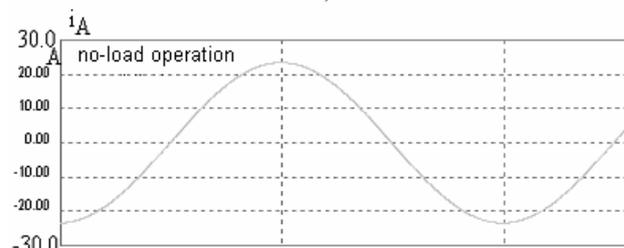
To prove impact of compensating device in stationary work regime, computer modulation with program PSIM of induction motor with power $P_N =10$ kW, 1500 rpm operation was made. In Fig. 5 oscillograms of consumed current from network are shown at no-load operation (b,) at no-load operation with capacitor bank in parallel (d), at rated loading without compensation (a), at rated loading with capacitor bank (b).

As we can see from Fig. 5(a), at rated loading without compensation current and voltage bias in phase is big. As a result of this fact big reactive power is consumed. In Fig. 5 (b) we can see that bias of current in phase is very big in no-load operation regime of the motor therefore, as a result of this fact consumed current from network is 0,75 from current in loading regime. In Fig. 5 (c) and (d) we can see from network consumed current at none compensated motor at rated load and in no-load operation. It is seen that

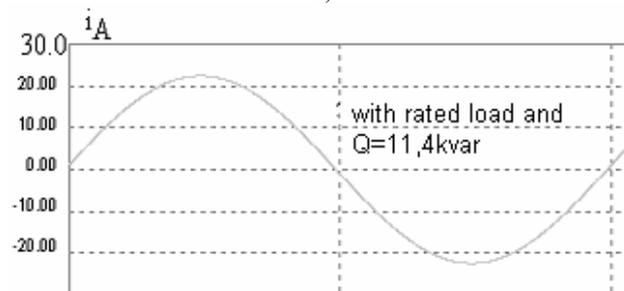
compensating capacitor power at rated load and in no-load operation differs only a bit (respectively $Q=11,4$ kvar and $Q=10,7$ kvar). In loading regime from network, consumed current in compensated case is smaller than no-load operation current in none compensated case. But in no-load operation consumption from network is only 2,3% compare to current in no-load operation in none compensated case.



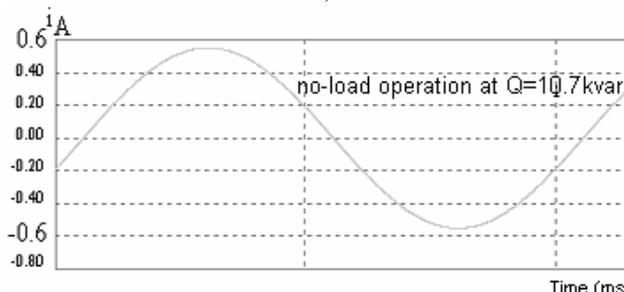
a)



b)



c)



d)

Fig. 5. Phase current and voltage oscillograms of the induction motor: a,b – without compensation at rated load (a), no load operation (b); c,d – with capacitor bank in parallel with load (c) and no-load operation (d)

As we can see from curves presented in Fig. 5, operative compensation at no-load regime is very important, when from network consumed current can be diminished to few values. It means that such operative compensation device is very important at the situation when load is changing close to rated and no-load operation (for example, electric saw). Compensation diminish from network consumed current average quadratic value in operation time, that significantly affects device loading and warm of supply network.

Conclusions

1. Regulated reactors together with none compensated capacitors can change reactive power balance smoothly and can be used to compensate reactive power caused by induction motors in stationary work regimes.
2. Induction motor is typical consumer of reactive power and consumed reactive power grows if loading grows. The bigger is rated power of the motor, the bigger

is relative growth of reactive power. Reliable expressions for calculation of relative reactive power dependent from different motor parameters are gained.

3. Capacitors must be chosen at rated regime, but reactive power of reactor must cover difference between consumed reactive power in rated and no-load regime. Result of operative compensation is that consumed current from network in no-load regime is very small.

References

1. Минин Г.П. Реактивная мощность. – Москва: Госэнергоиздат, 1963. – 88 p.
2. Кравчик А.Э., Шлаф М.М., Афонин В.И., Соболенская Е.А. Асинхронные двигатели серии 4А. – М.: Энергоиздат, 1982. – 504 p.

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J. Zakis, I. Rankis, A. Zhiravetska. Investigation of an Active System of Reactive Power Compensation for Induction Motors // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 6(70). – P. 11–14.

In the following paper there is analyzed possibility to change the power of compensation capacitors with thyristor regulated reactors. As an application of compensator asynchronous motor in steady-state regime is used. Using data from catalogues the usage of reactive power in asynchronous motor is researched. Charts that show changes of relative reactive power in different type asynchronous motors dependent on loading were acquired. Expressions for calculations of parameters of compensator have been also recommended. The required parameters of compensators are acceptable for operative compensation in steady state regime if load is changing. For process research computer modulation program PSIM is used. Using diagrams of phase current and voltage of the motor it is concluded that compensation effectively reduces network current especially in no-load operation. Ill. 5, bibl. 2 (in English; summaries in English, Russian and Lithuanian).

Я. Закис, И. Ранькис, А. Жиравецкая. Исследование системы оперативной компенсации реактивной мощности асинхронного двигателя // Электроника и электротехника – Каунас: Технология 2006. – № 6(70). – С. 11–14.

Рассмотрена возможность плавно изменять компенсационную мощность конденсаторов с помощью регулируемых реакторов. В качестве объекта компенсации принят асинхронный короткозамкнутый двигатель. По каталожным данным исследовано потребление реактивной мощности асинхронным двигателем в зависимости от номинальной мощности, степени загрузки, частоты вращения. Получены статистические выражения для расчета потребления реактивной мощности. Предложена методика выбора емкости конденсаторов и индуктивности реакторов. Компенсирование предложено проводить в стационарном режиме работы. Для проверки было проведено компьютерное исследование работы двигателя с компенсацией и без нее. Показано, что применение компенсации позволяет существенно уменьшить потребляемые от сети токи, особенно в холостом режиме. Ил. 5, библи. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Zakis, I. Rankis, A. Žiraveckaja. Asinchroninio variklio reaktyviosios galios operacinės kompensacijos sistemos tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 6(70). – P. 11–14.

Ištirta galimybė tolygiai keisti kompensacinių kondensatorių galią reguliuojamais reaktoriais. Kompensacijos objektu pasirinktas asinchroninis trumpojo jungimo variklis. Remiantis katalogų duomenimis, ištirtas reaktyviosios galios asinchroniniuose varikliuose panaudojimas. Pateiktos statistinės išraiškos, skirtos reaktyviosios galios panaudojimui apskaičiuoti. Pasiūlyta kondensatorių talpos ir reaktorių induktyvumo parinkimo metodika. Kompensavimą siūloma vykdyti esant stacionariam darbo režimui. Patikrai buvo atlikta variklio su kompensacija ir be jos darbo kompiuterinė analizė. Parodyta, kad kompensacijos panaudojimas leidžia gerokai sumažinti iš tinklo naudojamą srovę, ypač esant tuščiajam eigai. Il. 5, bibl. 2 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).