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Influence of Parameters of Induction Motor-Centrifugal Pump Units with Hydropaths Connected in Series on their Modes

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Abstract

Using the mathematical model of the pump station power supply system in steady-state modes developed by the author, the influence of the parameters of induction motor-centrifugal pump units with in-series-connected hydropaths of the pumps on their steady-state modes was studied. A comparison was drawn on the operation of a number of coupled units with different pump ratings. It was revealed that the difference in rated flow of the operating fluid in centrifugal pumps results in the fact that only the unit with the lowest operating fluid rated flow works effectively. Units with larger rated flow of the operating fluid are underutilized and work with a decreased efficiency in all modes. Viability of applying centrifugal pumps with minimal difference in operating fluid rated flow for induction motor-centrifugal pump units with in-series-connected hydropaths of the pumps was substantiated.

Keywords: power supply system; induction motor; centrifugal pump; pump station.

1. Defining the research problem selected for the study

At the present stage of mathematical modelling, there are no available effective models of a range of receivers consisting of inseparably connected devices of different physical nature with their automatic regulators taken into consideration. This does not allow making a comprehensive analysis of their modes and processes taking into account the mutual coupling that complicates development of automated control systems (ACS) and selection of their control functions. One of the tasks is to study the effect that the parameters of inter-coupled induction motor-centrifugal pump (IM-CP) units have on their modes.

2. Analysis of recent publications and studies on the issue

The effect of the ratings of the pumps of the inter-coupled IM-CP units on their modes is a topical issue from the point of view of generic approach. MIKE NET by DHI Water&Environment, powerful software available today, can be used to model hydraulic processes in drinking water supply systems. This software, along with other available applications, just establishes a relationship between the parameters and reference coordinates of the mode of the pump, pipes, etc. (flow, pressures) and main energy parameters and coordinates of the mode of the substations (electricity cost, kw demand). However, they do not make it possible to analyse, for instance, energy losses distribution in specific elements of the pumps (diffuser, volute, sealing, etc.), motors, their mutual effect (for instance, core saturation, harmonic components of current), influence on the power supply system, etc. Based on the analysis of experimental records of pump stations mode coordinates carried out in [1, 2, 3] it was defined that variations of pump flowrates in time are rather slow (except during the starts and stops of the equipment and emergency processes). That is why they can be considered as quasi stable values. Main part of energy consumption and considerable losses of energy

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take place right during these modes. And application of energy saving measures during these modes leads to a significant effect. The mathematical model proposed in [4, 5] allows solving these tasks for steady-state modes of IM-CP units.

3. Aim of the research

The research aims at studying the effect that the ratings of the pumps of induction motor-centrifugal pump units with in-series-connected hydropaths have on their modes, using generic approach.

4. Results and discussion

The electrical and hydraulic diagram of the pump station is presented in Fig. 1. As an example, two units connected in parallel by hydropaths were taken.

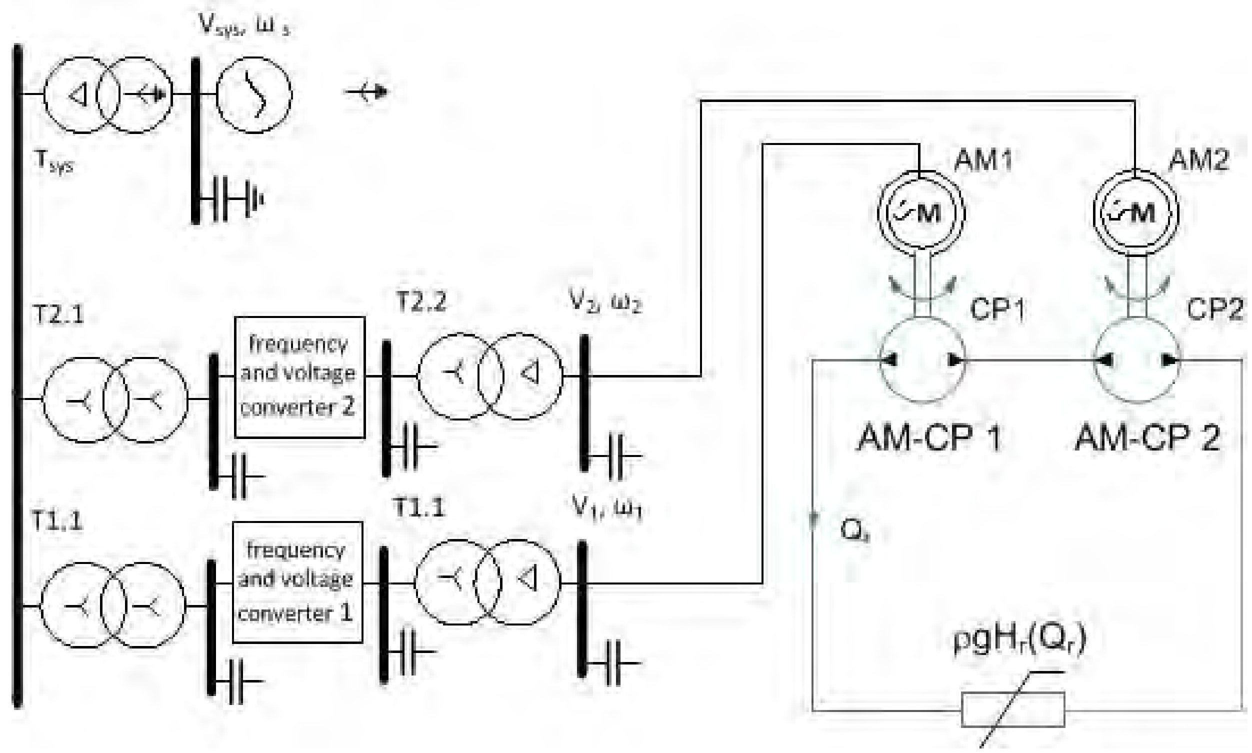

Fig. 1. Electrical and hydraulic diagram of the pump station

This study relies on the mathematical model of the pump station power supply system proposed in [4, 5]. Equation of state is written in arbitrary base units in orthogonal coordinates, separate for IM and CP, which are respectively rigidly bound with rotating magnetic field of the IM stator (d_s, q_s) and CP impeller (d, q). The mentioned model was adjusted for calculation of steady-state modes of two IM-CP units with in-series-connected hydropaths (Fig. 1).

The relationship between all the centrifugal pumps of the units and the hydro network is established on the basis of [4, 5]. The hydropaths of the two units are connected in series. Written in arbitrary base units [4, 5], equation expressing the relationship between them has the following form:

$$H_{CPn_1}\left(\sqrt{\left(H_{CPd_1}\right)^2+\left(H_{CPq_1}\right)^2}\right)+H_{CPn_2}\left(\sqrt{\left(H_{CPd_2}\right)^2+\left(H_{CPq_2}\right)^2}\right)=H_{CPb}H_r(Q_r)\,; \tag{1}$$

$$Q_{CPn_1}\sqrt{\left(Q_{22d_1}\right)^2+\left(Q_{22q_1}\right)^2}=Q_{CPn_2}\sqrt{\left(Q_{22d_2}\right)^2+\left(Q_{22q_2}\right)^2}\,; \tag{2}$$

$$Q_{CPn_1}\sqrt{\left(Q_{22d_1}\right)^2+\left(Q_{22q_1}\right)^2}=Q_{CPb}Q_r\,, \tag{3}$$

where for the ith IM-CP unit, Q_{22d}, Q_{22q} are projections of vector of output volume fluid flow rate; H_{CPd}, H_{CPq} are projections of vector of output pressure; H_{CPn}, Q_{CPn} are rated hydraulic lift and volume flow rate of the pump fluid, respectively; H_{CPb}, Q_{CPb} are base hydraulic lift and volume fluid flow rate, respectively; Q_r is output volume fluid flow rate; $H_r(Q_r)$ is static vertical lift of the hydro network.

For unambiguous distribution of the operating fluid between the units, functions of pressure control of in-series-connected hydropaths of the units are set [6]. In this case, this function is a proportional relationship between pump pressure H_{CPd}, H_{CPq} and rated pump pressure:

$$H_{CPn_i}\left(\sqrt{\left(H_{CPd_i}\right)^2+\left(H_{CPq_i}\right)^2}\right)=H_b k_{difH_i} H_r(Q_r)\,, \tag{4}$$

where for the ith IM-CP unit, k_{difH} is factor of pressure distribution between pumps with in-series connected hydropaths.

In this case, factors k_{difH} calculated using the method described in [6] are invariable. Their numerical values for this test case are presented in Table 2. Test calculation of a set of steady-state modes of the pump station depicted in Fig.1 was carried out by means of changing the total flow Q_r in the range 0.15 to1.25 while maintaining rated pressure. Steady-state modes were calculated according to [6].

For test calculations a power system with U_{sys}=110 kV, Skz_{sys}=1,000 MVA and ТДН-40000/110 transformer was used. Capacity values were selected in the process of calculation so as to avoid overcompensation of reactive power of IM in the calculation range. Other units whose parameters were used for test calculations are listed in Table 1.

Table 1. List of units used for test calculation

Item	Centrifugal pump	Induction motor	Transformer
1	14 НДсН	МА-38-61-6	ТСЗ-250/10
2	QG 300/2/100	4АЗМВ-1600/6000У2-5	ТМ-2500/10
6	20 НДсН	ВАО2-550	ТМ-1000/10Т
9	НМ 3600-230	2АЗМП-2500/6000У4	ТМ-4000/10

Table 2. Numerical values of pressure and flow rate distribution coefficients of the pumps

Equipment configuration	k_{difH1}	k_{difH2}	Equipment configuration	k_{difH1}	k_{difH2}
2.2	0.500	0.500	1.6	0.580	0.420
2.1	0.063	0.937	1.9	0.243	0.757
2.6	0.954	0.046	6.9	0.189	0.811
2.9	0.828	0.172	---------	---------	---------

Test calculations were conducted for various combinations of IM-CP units. To solve the nonlinear system of finite equations of the mathematical model, a differential method of finding zeroth-order approximations in the form of h-characteristics [7, 8] was applied. Mathcad system was applied using Levenberg–Marquardt algorithm [9]. The results of calculating steady-state modes of the pump station (Fig. 1) are presented below.

Plots of some main indicators versus operating fluid flow rate and difference in pump ratings allow analysing the effect of ratings of the pumps of the units on their modes (Fig. 2–7). Additional indicators – load factor of the pump and difference in pump rated flows – were used for the analysis:

$$k_{CP_i} = P_{CPg_i} / P_{CPn_i}\,; \tag{5}$$

$$k_{\Delta QCP_i} = \max\left(Q_{CPn_1} / Q_{CPn_{i+1}}; Q_{CPn_{i+1}} / Q_{CPn_i}\right) - 1, \tag{6}$$

where for the i^th^ IM-CP unit P_{CPg}, P_{CPn} are hydraulic and rated hydraulic power of the pump.

The results obtained show that for the operation of a group of IM-CP units with in-series-connected hydropaths of the pumps, only the unit with the lowest operating fluid rated flow works effectively. Units with larger rated flow of the operating fluid are underutilized in all modes. Their efficiency and load factor in particular drop dramatically as the difference in operating fluid rated flow rises. Power factor is practically non-affected by difference in pump rated flow. The difference in rated pressure was not found to have effect on mode indicators.

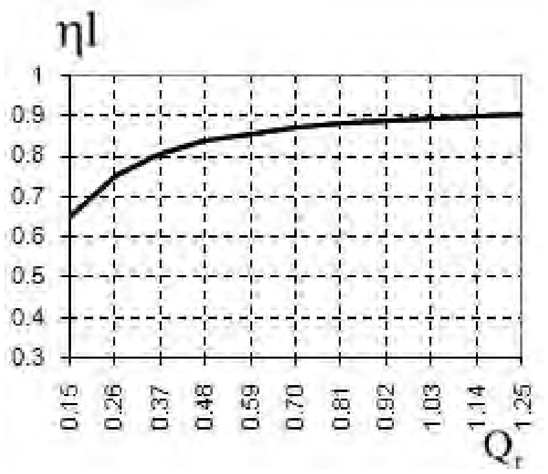

Fig. 2. Efficiency of the 1st IM-CP unit

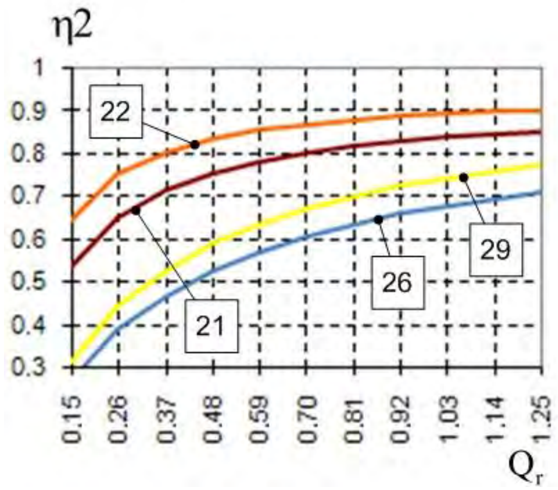

Fig. 3. Comparison of efficiency of the 2nd IM-CP unit in operation with other units

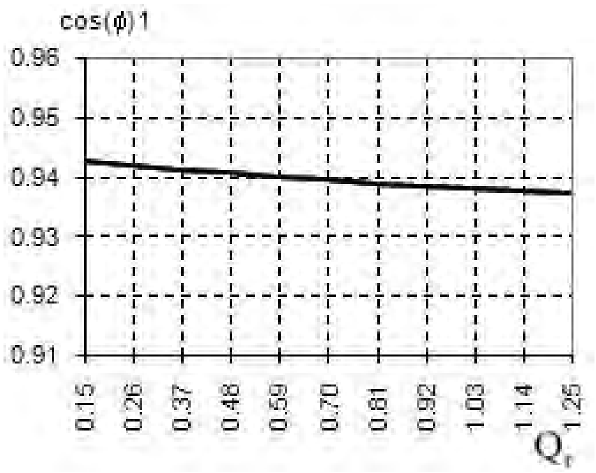

Fig. 4. cos(φ) for of the 1st IM-CP unit

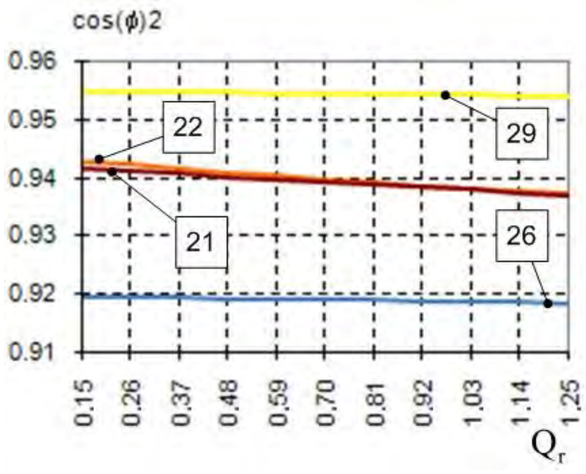

Fig. 5. Comparison of cos(φ) of the 2nd IM-CP unit in operation with other units

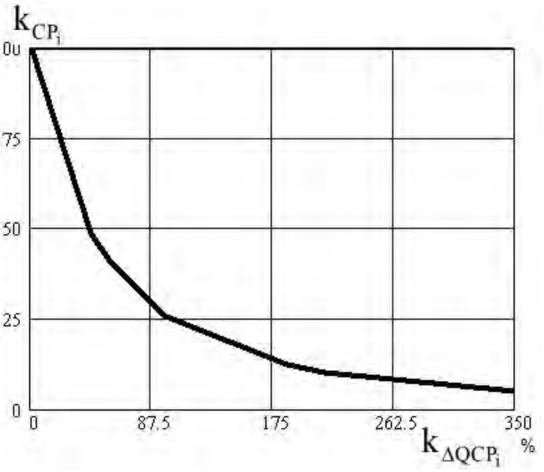

Fig. 6. Pump load factor of the underutilized unit plotted vs. difference in operating fluid rated flow

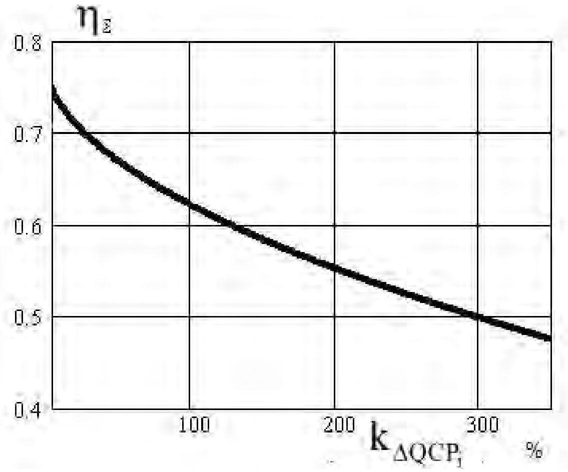

Fig. 7. Overall efficiency of two units plotted vs. difference in pump rated flow

5. Conclusion

The paper analysed and compared the effect of parameters of induction motor-centrifugal pump units with in-series-connected hydropaths on their modes. Difference in pump rated flow was found to have a negative impact on load factor of the units and to lower their efficiency considerably. Therefore, when selecting equipment for induction motor-centrifugal pump units with in-series-connected hydropaths, use of centrifugal pumps with minimum difference in operating fluid rated flow is a viable option.

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Вплив параметрів агрегатів асинхронний двигун – відцентрова помпа з послідовним сполученням гідротрактів на їхні режими

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Анотація

За допомогою створеної автором математичної моделі електропостачальної системи помпової станції в усталених режимах досліджено вплив параметрів агрегатів асинхронний двигун – відцентрова помпа з послідовним сполученням гідротрактів помп на їхні усталені режими. Наведено порівняння роботи низки пар агрегатів із різними номінальними параметрами помп. Виявлено, що розбіжність номінальних витрат робочої рідини відцентрових помп призводить до того, що ефективно працює лише той агрегат, номінальна витрата робочої рідини якого є меншою. Агрегати з більшою номінальною витратою робочої рідини працюють недовантаженими та зі зниженим коефіцієнтом корисної дії в усіх режимах. Обґрунтовано доцільність застосовування відцентрових помп з мінімальною розбіжністю номінальних витрат робочої рідини для роботи агрегатів асинхронний двигун – відцентрова помпа з послідовним сполученням гідротрактів помп.

Ключові слова: електропостачальна система; асинхронний двигун; відцентрова помпа; помпова станція.