Determining the Electrical Losses in the Electrical Supply Line of a Sprinkler Using Autonomous Asynchronous Generator

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Abstract. The use of an asynchronous generator to power the electrical equipment of the sprinkler is a comprehensive solution that allows you to reduce electrical losses in the supply line. The problem of reactive power compensation for sprinkler machines can be solved by dividing capacitor units into main and additional, the main one is to create the required excitation current in the asynchronous generator, and the additional one is to compensate for the reactive component of the electric motor current. Moreover, an additional unit is installed directly at the outputs of the booster pump to unload the line, and the main capacitor unit is installed near the asynchronous generator.

1. Introduction
The restoration and development of the reclamation fund (reclaimed land and reclamation systems) is a priority task in the Krasnodar Territory in accordance with the long-term regional target program "Development of reclamation of agricultural land in the Krasnodar Territory for 2013-2020", which implies the introduction of new and modernization of existing irrigation systems. Sprinkling is widely used for irrigation, because it creates the necessary water regime of the soil without disturbing its structure. Together with the use of closed pipelines instead of temporary irrigation canals, this allows for an increase in the utilization rate of the land. It is possible to maneuver irrigation rates in a wide range - from 50 to 900 m\(^3\) / ha without water loss for depth filtration.

Autonomous power supply for electrical equipment of irrigation units during the season is difficult, since operator control is required to start or stop. This leads to the need to lay a separate power supply line for these units with the design of a separate transformer substation, which in turn leads to significant costs [1,2].
With advantages such as increased reliability, smaller weight and dimensions, high power quality, the use of asynchronous generators restrains the insufficient degree of voltage and frequency stabilization [3-6], which leads to the need to use additional control circuits or the use of an inverter converter, since when a high-power load is turned on, de-excitation of the asynchronous generator. This is especially important when turning on the motor load, since the starting current of an asynchronous motor can reach 7-10 currents more than the rated one, which will immediately lead to demagnetization of the generator [7].

Reducing electrical losses in the line is especially important for sprinklers, since the supply line of the electric motors of the drive carts and the booster pump can reach 700 m, which leads to an overestimation of the cross-section of the supply cable.

The establishment of a reliable source with an asynchronous generator of a sprinkler machine, which allows starting the motor load with a simultaneous decrease in the reactive component of the starting current in the supply line, is a vital task.

2. Issue statement
Reactive current not only takes away from the active current a part of the network bandwidth, but a certain part of the active energy is spent on its passage through the wires, since the power losses are determined as \( \Delta P = 3R \cdot I^2 \), where \( I \) is the total current [8]. The transfer of reactive power affects the voltage modes, the resulting voltage decrease leads to an even greater increase in electricity losses and a decrease in the transmission capacity of the lines. Therefore, a decrease in the reactive component of the current leads to a significant decrease in electrical losses for sprinklers, since they are powered by long low-voltage power networks. To compensate for reactive power in electrical networks for voltages up to 1 kV, as a rule, capacitor banks (BC) are used, which are connected in the form of local compensation to the load terminals. The criterion for the optimal distribution of capacitors in the electrical network is the minimum of the total active power released in the conductors when reactive power passes through them. It is advisable to distribute capacitor installations in such networks in proportion to reactive loads.

The power supply of the sprinkler is carried out through the main network with branches to power the electric drives of the trolleys and the booster pump. The cost of a BC is a nonlinear function of its power, therefore, reducing the required capacity of capacitor banks for exciting an asynchronous generator and compensating for reactive power is an urgent task.

To reduce electrical losses in an asynchronous electric motor, a method of starting at reduced voltage is known [9]. Lowering the voltage can be carried out by switching the stator winding using a switch from the normal circuit \( \Delta \) to the starting circuit \( \Upsilon \). In this case, the voltage applied to the phases of the stator winding decreases by \( \sqrt{3} \) times, which leads to a decrease in phase currents \( \sqrt{3} \) times and line currents by 3 times. At the end of the process of starting and accelerating the engine to the rated speed, the stator winding is switched back to the normal circuit or voltage control devices [10]. The disadvantage of these starting methods by lowering the voltage is a significant decrease in the starting and maximum motor torques, which are proportional to the square of the applied voltage, therefore this method is well suited for starting a booster pump with a square-law characteristic of the increase in the moment of resistance with increasing speed.

Thus, the reduction of the starting current of the electric motor together with the compensation of the reactive current in the power supply line of the sprinkler machines due to the excitation capacitors of the asynchronous generator is a complex solution to reduce electrical losses.

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3. Materials and methods
A characteristic feature of the autotransformer stator windings of an asynchronous generator is the ability to connect capacitors to a higher voltage, as a result of which the required excitation
capacitance decreases, while part of the stator winding of one phase is used to excite the generator. A generator with such a stator winding circuit can be connected both to an autotransformer star (in this case, the voltage at the H terminals will be 380 V) and in a star-delta (the voltage at the H terminals will be 220 V) [11]. It follows that when a standby power plant with an asynchronous generator is turned on to power the electrical equipment of a sprinkler with a star-delta stator winding circuit, followed by switching to an autotransformer star, it will reduce the starting current, while the starting capacitance of the excitation capacitors is significantly reduced.

It is advisable to place additional capacitance of excitation capacitors to compensate for reactive power in the line at the terminals of the electric motor (for a sprinkler machine, electric motors of trolleys and a booster pump). We will calculate this capacity for the cases of starting the trolley engine (0.55 kW) and starting the booster pump (5.5 kW). Obviously, it is necessary to select the capacitance of the capacitor in such a way as to compensate the starting reactive current of the induction motor, and after starting, leave the working capacitor of a smaller compensating capacitance turned on.

Taking into account the voltage across the capacitors when connected in a triangle, the resistance and the required capacitance of the capacitors [12]:

\[ x_c = \frac{U_c}{I_p} = \frac{462}{38.8} = 13.5 \text{ Ohm; } C = \frac{10^6}{\omega x_c} = \frac{10^6}{314 \cdot 13.5} \approx 235.9 \mu \text{F}. \]

Electrical losses in the case of power supply of the sprinkler can be divided into three components - in the electric motor \( \Delta P_m \), in the line \( \Delta P_l \) and in the generator \( \Delta P_g \).

To assess the electrical losses during the start-up and operation of the sprinkler booster pump, we will use simulation in the SimInTech software package [13].

The model of an asynchronous motor in the SimInTech software package is based on an L-shaped equivalent circuit with an external magnetizing circuit shown in Figure 1. In this diagram, the rotor parameters depend on slip, to take into account the effect of current displacement along the length of the slot (or in the starting and working windings). The model is made in a positive sequence and provides the calculation of the effective values of voltages, currents and powers [14].

\[ E = I_p R_2(s)(1 - s)/s \]

**Figure 1.** Induction motor equivalent circuit.

The function that determines the dependence of the rotor parameters, and hence the torque characteristic, on slip is given as follows:

\[ R_2(s) = R_{20} + (R_{21} - R_{20}) s^a \]

\[ L_2(s) = L_{20} + (L_{21} - L_{20}) s^a \]  \hspace{1cm} (1)

where “a” is the coefficient of the degree of the moment characteristic, which is selected experimentally (If the nature of the moment characteristic is not known, then a can be taken equal to 1).

The electromagnetic moment of an induction motor is determined taking into account the voltage and frequency of the supply network \( f_1 \) by the formula:
it is possible to set the moment of resistance of the mechanism through the input port or use the built-in dependencies by setting the load factor \( K_z \) and the type of characteristic of the mechanism \( \text{TypeMc} = 1 \)

\[
M_c(s) = M_0 + (K_z - M_0) \left( 1 - \frac{s}{1 - s_n} \right)^2
\]

The equation of motion of the rotor of an induction motor is as follows [15]

\[
T_j \frac{d\omega}{dt} = M_a - M_c
\]

Let’s set up the asynchronous motor unit according to the rated power of the booster pump 5.5 kW, for which it is necessary to define and set in the SimInTech software package: Type; Rated power 5.5 kW; Rated voltage 0.38 kV; Rated power factor 0.86; Rated efficiency 85.5%; Rated speed, 1360 rpm; The multiplicity of the maximum torque, 2.2 p.u.; The multiplicity of the starting torque, 2 p.u.; Multiplicity of starting current, 7 p.u.; Torque characteristic degree coefficient 1.8; Number of pole pairs 2; Moment of inertia, 0.017 kg • m²; Rated power supply frequency, 50 Hz; Simulate the moment of resistance, Yes; Load factor 0.8; The initial moment of resistance, 0.3 p.u.; active and reactive stator resistance, \( R_1 \) 1.2 Ohm, \( X_1 \) 1.55 Ohm; reactance (inductance) of magnetization \( X_0 \) 54.35 Ohm; active and reactance of the rotor \( R_2 \) 0.77 Ohm, \( X_2 \) 2.48 Ohm.

Line resistances are determined by specific indicators per 1 km, calculated for a given nominal voltage and line design \( (r_0 \text{ and } x_0) \):

\[
Z = z_0L = (r_0 + j x_0)L
\]

The loss of active power in the branch of the sprinkler’s power supply is determined by the formula:

\[
\Delta P_i = 3I_i^2R_i
\]

and in any group of \( m \) branches it is determined by the sum of active power losses in all branches

\[
\Delta P_m = \sum_{i=1}^{m} \Delta P_j = 3 \sum_{i=1}^{m} I_i^2R_i
\]

4. Results and discussion

The model (Figure 2) provides for the measurement of line currents, power supply voltages, phase currents and line voltages of the induction motor and the current of the capacitor bank. During start-up and steady-state mode, the current consumed by the IM, its developed torque and rotation speed are recorded in time. The model considers - direct start-up of an asynchronous electric motor, and start-up of an asynchronous electric motor at a reduced voltage of 220 V with reactive current compensation at start-up (switching on of starting capacitors) and steady state (switching on working capacitors) a power supply line with a length of 300 m and a cross-section of 10 mm². Disconnection of starting capacitors with a capacity of 484 \( \mu \)F (since in the model the capacitors are connected by a star) occurs after 0.0825 s.
The parameters of the power supply line are laid down in the R-L resistance block of the simulation model and depend on the length of the line, with an increase in the length, the resistance and inductance of the line proportionally increase.

\[ \Delta P = P_1 - P_2 \]

**Figure 2.** Simulation model for assessing electrical losses in the power supply line and the electric motor at start-up and steady state.

Losses in the power supply line (Figure 3,4) are defined as the difference in the powers measured at the source and at the electric motor by blocks P, Q for calculating the instantaneous values of the active and reactive power of the three-phase circuit based on the instantaneous values of currents and voltages \( \Delta P = P_1 - P_2 \).

**Figure 3.** The result of modeling the change in power losses in the power supply line (300 m) when starting an asynchronous electric motor.

**Figure 4.** The result of modeling the change in power losses in the power supply line (300 m) with the inclusion of compensating capacitors.
The result of simulation showed that a decrease in voltage leads to a decrease in electrical power losses in the electric motor by almost 3 times, and when the compensating capacitors are turned on, due to a decrease in the reactive component of the current, it allows to reduce electrical power losses in a line with a length of 300 m of power supply to 1000 W at start-up, and in steady state up to 142 W.

5. Conclusion
The mode of operation of sprinklers provides for frequent starts of asynchronous motors of trolleys and a booster pump. Starting currents can exceed 7 times the nominal, and the reactive component of the current can be 2 times higher than the active one, which leads to the need to overestimate the cross-section of the supply line, which can reach 700 m. the installation of a capacitor bank is a technological necessity, but which can be used to compensate for the reactive component of the current.

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