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Safe Energy using Hydraulic System Analysis at a Hydropower Plant

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ABSTRACT

The Hydro-PowerStation is one of the keys (important) sources of electricity, and it has a digital governor, which improves production efficiency over mechanical governors. This research looked at the hydraulic turbine, found flaws such as oil leakage from the pumps utilized, calculated the amount of energy consumed, and worked to reduce it by measuring the losses and monitoring the poor process during periods of high water load of up to 83%. As a consequence of the research, it was discovered that the amount of energy consumed had decreased by 20%, by employing well-made, effective pumps for each unit according to its use, oil leakage in all units is reduced.

1. Introduction

As natural fuel resources continue to dwindle, fuel prices rise steadily, and pollution levels increase, research into methods to reduce energy consumption is a rapidly developing field of study. There are three main types of power transmission systems: electrical, mechanical, and hydraulic [1-3]. A power hydraulic system's energy savings is a promising technological advancement because of its better potential for specific power production. Additionally, safety-critical equipment is used in power hydraulics. A hydraulic system's energy-saving process can be divided into three categories: system design, increasing component or product functionality, and system loss reduction [4,5].

The hydraulic system's energy efficiency is enhanced by configuration changes made as part of the system's design. To achieve this goal, either the best available equipment is chosen or cutting-edge system design or control techniques are applied. The control methods are typically used on hydraulic pumps and motors, control valves, and actuators on mobile equipment [6,7]. For instance, swash plate control on a variable displacement pump, motor, or actuators; various valve-controlled approaches; and power supply unit control are all viable options [8-10]. In addition, the efficiency of the system is determined by the combination of the hydraulic system components chosen for a given application and user need [11].

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Hydropower is an attractive renewable energy choice because it provides various benefits over conventional electrical power. Because they do not require high temperatures to function and don't rely on expensive fuel sources like fossil or nuclear, hydroelectric facilities offer cheap operating and maintenance expenses [12,13].

1.1 The Digital Governor

The Kaplan principle is used in Kaplan hydropower. It applies to any unit where the opening of the wicket gate and the angle of the runner blades are timed to widen the range of ideal performance. It is important to note, however, that the Kaplan turbine's adjustable wicket gates work in tandem with the variable runner blades to ensure optimal performance regardless of the head, flow, or load. In many contexts, this idea will be useful [14].

A governor regulates the water flow and thus the speed and frequency of the generator. Additionally, it makes sure the turbine's water supply is adequate and the system's power requirements are met [15].

Any system feature that can be measured by a transducer, switch, or contact can be regulated by a digitally regulated governor, including speed, output of unit, flow, and level of water. The fundamental benefit of the digital governor is its adaptability and the ease with which adjustments may be made. It also makes it simple to connect to other computer systems [16].

A digital governor can carry out a wide range of additional control tasks that mechanical and analog governors cannot. The following are some of the features that digital governors can offer [17]

i. Adjustable power and speed.
ii. Volt-ampere-reactive (VAR) control is a feature of several digital governors.
iii. For either headwater control or tail water management, there are numerous different control requirements.
iv. Due to environmental concerns or water supply constraints, minimum flows may be required.
v. Digital governors can find turbine creep when they are used with zero velocity speed sensors and software logic.
vi. The sequencing of governor startup, braking, and shutdown is commonly controlled by relays. In situations where numerous units need to be sequenced, started, or stopped at specific times to regulate ponding, irrigation, or scenic water flow, digital control increases sequencing options and makes adjustments simple.

In this study, hydroelectric power plant machinery, including volumetric pumps, hydraulic flows, and speed governing systems, are examined in terms of their dynamic operation. The need to update this system, shortening the time it takes to do its job, and reducing wear and damage to the parts of the pressurization subsystem are what make it happen. The goal of this research is to come up with ways to improve electric motors, pressurization pumps, and speed governors in these power plants so that they use less power.

1.2 Station Description

The hydroelectric power station SHEPS in Samarra is located roughly 120 km north of Baghdad. It is located on the Tigris River. It plays a significant role in Iraq's power production. Three vertical turbines make up the station. (Kaplan type). These turbines operate with a 21-metre water head. These three electric generators, each with a 28 MW output and operating at an 11 KV voltage, are directly connected to the three turbines. Three units together provide 84 MW of power.

The SHEPS speed governor system has huge dimensions, requires a little hydraulic fluid, and demands prompt and secure actuation. The system can be broken down into smaller systems due to its complexity, which makes the circuits simpler to comprehend and study. The pressurization unit, accumulators, valves, actuators (servomotors), servomotor control mechanisms, and air auxiliary system are the main subsystems. The wicket gate closing time control valve, the servomotor hydraulic lock, and the over speed sensor valve are also crucial to the speed governor's safe operation.

2. Methodology

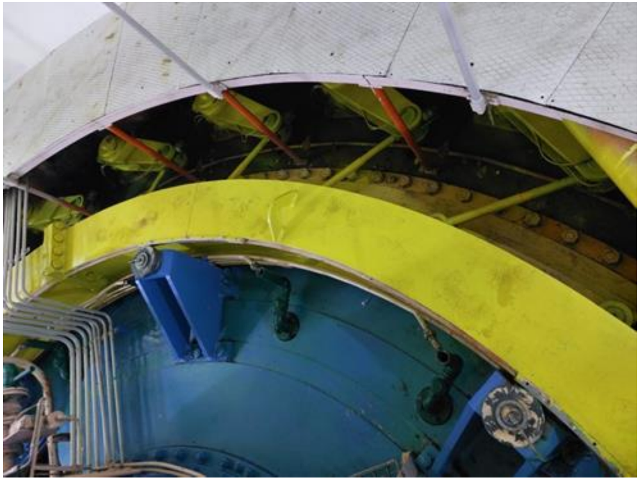
2.1 Theoretical Analysis

The rotation of a synchronous machine is one frequent method of generating electric energy; this machine converts mechanical energy from the driver and needs to be rotated at a constant pace in order to provide a frequency that is suitable for consumers [18]. Turbines are the most common engines for these generators, whether they are powered by water or some other source of energy. A speed governor is necessary because these machines are vulnerable to a change in demand on the electric system, which causes a divergence in the electric load. This research examines the speed regulator that operates in the water entry section in order to better manage the speed of Kaplan turbines. Hydro Kaplan turbines use a wicket gate to regulate water flow fluctuation. Closed or open, the gate reduces or expands the turbine's inlet area by using a series of rotating vanes. The wicket gate, also known as the distributor, is operated by a collection of rods attached to the regulating ring. The hydraulic servomotors that control the speed of this ring move it [19–21]. The hydraulic fluid volume required to operate the speed governor system is medium, and it must be done in a way that is both safe and quick. Because the circuit is complicated, it can be broken up into subsystems that make it easier to understand. See Figure 1.

Main subsystems include the pressurization unit, accumulators, valves, servomotor control mechanisms, servomotor actuators, and the air auxiliary system. The wicket gate closing time control valve, the shaft's overspeed device triggers the overspeed sensor valve, and the servomotor hydraulic lock are also very important parts of the speed governor's safe operation.

Many of the components of the system are depicted in Figure 2. To move the wicket gates, an actuator called a servomotor is stationed 46 meters above ground in Figure 2(a) (elevation 46). Figure 2(b) depicts the electric motors powering the speed governor's pressurization pumps; the pumps, along with the rest of the speed governor's hydraulic components, are housed in the sump tank depicted in Figure 2(c). At this level (48), you'll find both the sump tank and the accumulator's Figure 2(d). In Figure 2(e), the intermittency valve is shown to be the hydraulic component that controls the intermittent work of pressurization by directing the pump's discharge. The pressure detector valve, which controls the operation of the intermittent valve based on the pressure in the accumulators, is depicted in the same Figure 2(f).

(a) Shaft (b) Blades Kaplan turbine



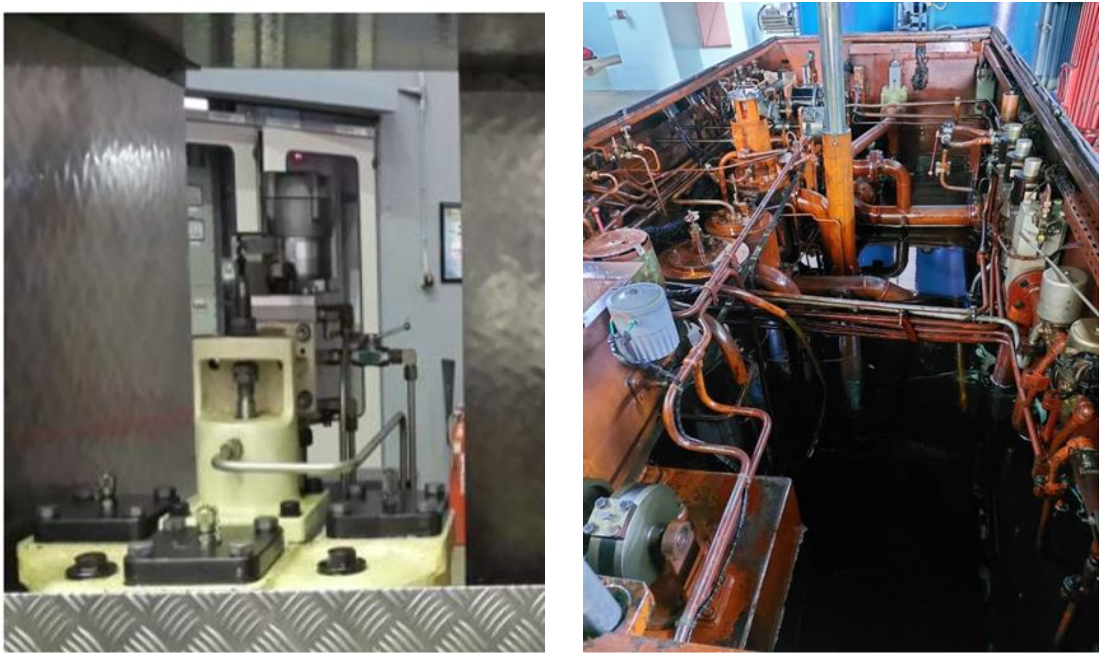
(c) The opening and closing ring related to the servomotors

Fig. 1. Kaplan turbine

(a) The servomotor (b) The drivers of pressurization pumps

(c) The accumulators

(d) The sump Tank



(e) The pressure detector valve and the intermittence valve

(f) The governor system

Fig. 2. Speed Governor System component

2.2 Accumulators of Hydraulic

Because the pressurization intermission time is estimated using measurements from the pressure sensor mounted on this tank, a description of hydraulic accumulators is included here. Further, the air oil pressure vessel allows the pumps to run at a variable pace since it allows the system to function. For a basic hydraulic system, the pressurization pumps are sized to match the largest actuators. In order to make the system more cost-effective and reliable, a hydraulic accumulator, which minimizes pump requirements, is incorporated into its logic of work [22]. When the system is vast and requires frequent actuation, like in the case of a speed governor, this becomes increasingly important. There are hydraulic systems that need to keep a consistent, narrow pressure range working for a very long time. Hydraulic circuits are notoriously difficult to maintain a constant pressure in due to leakage from its components, whether internal or external. The speed governor fits this description, and in addition to leaking, it also requires a large amount of fluid to be supplied to the system's leaks for a short time period during operation. The role of accumulators is to dampen the impact of any sudden changes in pressure brought on by a halt in flow. Depending on the system's actual state of operation, they can either counteract thermal expansion or compensate for thermal contraction [23].

A gas-pressurized accumulator, known as an air-oil tank, performs the aforementioned tasks within the speed governor system. All of the pumps' working modes are regulated by the supervisory system based on the pressure in this accumulator. When the pressure within the air-oil tank hits 3.5 MPa, a pressure-sensing component will cause the pump to switch to full load. Since the pressure detector valve is essentially mechanical, it can be impacted by a variety of things, including clearances, pressure variations in the system, regular wear and tear, and misalignment. When the valve is turned on, the oil pressure inside the intermittent valve is released. This valve controls the pump's output, directing fluid to the heat exchangers or the main pressure line to enable fluid recycling. For reasons of safety, both the tank's internal pressure and a level sensor can set off alerts. When the oil level in the tank reaches predetermined levels, an electrical signal is sent to the supervisory system via this sensor's level switches.

2.3 Volumetric Pumps

It is helpful to understand how volumetric pumps work in order to appreciate their role as the hydraulic accumulator. If you know how the pumps work, you can extrapolate how changes to the pressurization interval will affect the system, and you can pick a replacement pump with the right characteristics for your fluid that will be able to provide the required flow while keeping the system's working pressure constant. Positive displacement pumps, as opposed to centrifugal pumps, which deliver energy to the fluid by increasing its velocity, are used to generate the required pressure in hydraulic systems. Flow constraints on the piping leading back to the pump determine the final fluid pressure [24]. The pressure increase induced by turning off these pumps necessitates the installation of safety mechanisms and the construction of a sturdy pipeline [25]. Before choosing a pump, it's crucial to have a firm grasp of the operational parameters. Discharge pressure, speed expectations, temperature, noise level, motor driving characteristics, flow rate, and viscosity are some of the conditions to consider [26]. The advantages of screw pumps include their adaptability to a broad variety of fluids, pressures, and viscosities. Some designs can handle air and other gases getting inside, low internal speeds, little churning and foaming, little mechanical vibration, little noise, and flow without pulsations [25]. The enhanced rotor design directly contributes to the improvement in these characteristics. The pumps can have one rotor or multiple rotors, and the latter can be further divided into timed and untimed variations. A timed pump typically has two rotors, one of which is powered and the other of which is rotated by a set of gears. By being either inside the pump's housing or in a separate casing, these gears can avoid contact with the pumped fluid. The rotors of an untimed type of screw continuously exchange the driving force due to the rotors' mating thread geometries. This word is typically used to refer to pumps with three rotors, one of which is a powered rotor that meshes with two other rotors, also referred to as idlers. The housing carries the axial loads. A power rotor and two lateral rotors, each with a number of screws, make up the speed governor's pressurisation pump, which is similar to what has been mentioned before. The screws' helical thread helps ensure a tight fit and steady engagement of the mechanism. The ability of the rotors to mesh and enhance flow is crucial for pump efficiency. This flow is axial across the pumping sections, unlike traditional rotary pumps [24,27,28].

Evaluation of the theoretical power (W_t) required to drive the pump rotor is required for further investigation.

$$Q_t = S_d \times N_b \qquad \rightarrow \qquad S_d = \frac{Q_t}{N_b} \tag{1}$$

$$W_t = \rho Q_t g H_p = Q_t \Delta P \tag{2}$$

The geometry of the rotor determines the difference in displacement per revolution for a vane pump, gear pump, lobe pump, and screw pump, all of which may be modelled using the same equations.

2.4 Induction Motors

To understand the induction motor's current and beginning torque behaviour in this section, a thorough understanding of motor drives is essential. Because the suggested improvement in this study reduces the number of pressurization cycles and the total amount of time the electric motor operates at full load to pressurize the oil, a significant reduction in energy consumption is achieved. Knowing the driver motor's angular velocity and making an estimate of the output power of an induction motor are both crucial for the next set of results. Eq. (3) and Eq. (4) return the motor's speed (Nm) and electrical power (W_{el}).

$$W_{el} = \sqrt{3} V_i I_i \cos\varphi \qquad \text{(W)} \tag{3}$$

$$N_m = 120 \times \frac{f}{P} \qquad \text{(RPM)} \tag{4}$$

Three-phase induction motors are widely used as pump drives in industrial settings due to their low cost, ease of control, robustness, and efficiency. A rotor and a stator make up the basic building blocks of an induction motor. When the stator is wired into the power grid, electromagnetic induction causes a flux of current to flow through the rotor [29].

The torque and current curves acquired in this study are of particular interest, as they span the transition from the beginning of the motor's operation to its steady state functioning. This is especially important for the governor, whose starting current might be three to four times that of continuous operation. Additionally, the electrical panel contains an excess current that disconnects power to the motors and trips the producing unit if two pumps need to run simultaneously.

It was important to discover the variables affecting how pressurization pumps operate in order to construct this article. The study's interpretation of the hydraulic designs found in the dam's technical library was the first step. Thanks to these diagrams, the author is able to understand the superfluous assembly needed to pressurize the oil. The study's interpretation of the hydraulic designs found in the dam's technical library was the first step. The author is able to comprehend the unnecessary assembly required to pressurize the oil thanks to these diagrams. It was confirmed that these pumps cannot be left inactive for an extended period of time and that the electric motor casing must always be warmed. In order to lubricate the bearings, the housing needs to be heated; otherwise, the grease will become too thick and the engine won't start.

Based on these findings and the author's background in maintenance engineering, the hydraulic accumulator pressure was determined to be the key variable in explaining the correlation between the pressurization pumps' intermittent behaviour and the tank oil level dropping. As was already indicated, the hydraulic accumulator is in charge of supplying the internal leakage that occurs in every generating unit and results in a variance in the intervals between pressurizations. This happens as a result of the varying clearances between the components of the hydraulic system that may be present under various working conditions for the equipment.

The level of the speed governor's air-oil accumulator is reflected in the data gathered by the monitoring system. All generating units collect data on tank pressure for use as a safety alarm trigger, which might result in varying wear and lifetimes for the primary pressurization pumps.

Measuring the oil level on each generating unit in order to determine the leakage flow. Use the sensor's output measurements. The author found a link between the change in the oil level in the accumulator tank and the pressure that was measured by the monitoring system. As a result, it becomes possible to calculate the leakage flow that escapes the tank while it is operating steadily.

The data collected by the supervisory system has undergone some statistical processing, and an algorithm written in Matlab® has been put in place to facilitate this. The algorithm uses comparisons of nearby data points to get the greatest and minimum values in the vector. It is possible to estimate the pressurization intermission time, although this method is invalid for the pressurization time. The smallest sampling time of the supervisory system and the pressurization duration both range from 42 to 58 seconds. The measuring error with this sample time is unacceptable due to the dynamics of the sensor or the pressure behaviour inside the tank. In order for the findings for the interlude periods to be acceptable during the pressurization time, the author specified a maximum standard deviation of 10%. During the two days of operation, the initial findings were calculated with 10 seconds between measuring stations. A finer analysis was required since the calculations found in some generating units was heavily distributed. The standard deviation was acceptable in all tests with sampling times of 2-5 sec. under conditions of constant generated output power unit, as indicated in the results in the following section.

The algorithm's most important results are the decrease in oil volume between pressurizations, the leakage flow from the hydraulic accumulator, the standard deviation, and the interval times in minutes for all generating units.

The evaluation's findings are essential for making the right choice of machinery. The primary goal of this work is to identify a steady-state pump based on the normative requirements of IEEE Std. 125 and IEEE Std. 1207 [30,31]. Makeup pumps, sometimes known as pony pumps, are used to replenish oil lost through leaks in bigger generators' hydraulic systems during normal operation.

3. Discussion of the Results

The information presented in Table 1 is the end result of the methodology in the previous section. The results of the computation were analyzed with a sampling interval of 5 seconds on October 14 between 15 hr and 22 hr; the information utilized to calculate the generative unit 7 break occurred on November 14 between 15 hr. and 22 hr. The percentage of time the unit's output power was over 85% is quite high. In all generating units, the metrics' variance fell below allowable bounds; hence, this time of year was selected as having the highest or maximum load. When the producing unit is running normally, the servomotor displacement can have a significant impact on the interval between pressurizations, leading to inaccurate data interpretation. When applied to all units, Table 1, the global analysis reveals which pieces of machinery should be put to work. When the servomotors are in a fixed position of operation, Makeup pumps help reduce the lead pump's on-and-off times, as per IEEE Std 1207. In steady-state settings, the cosmetics pump should be able to supply twice as much oil as is being used. Any surplus can be sent through a kidney loop filtering device to help keep the oil pure. The goal of this layout is to standardize on pieces of gear that can all work together to meet the required flow rate, which in turn can either raise the quality of the oil or lessen the workload on the primary pump.

Table 1
Results for time of Intermission in all generating units

Units	Intermission time (min)	Standard Deviation (min)	Percent Deviation (%)	Leakage volume (m^3)	Leakage flow(l/min)
1	5.3	0.35	6.80	0.62	116.5
2	6.2	0.40	6.50	0.53	84.00
3	4.8	0.33	6.80	0.52	106.70

The primary pump drives are powered by the energy that an installation can generate for the system's 45 KW motors. The energy requirements for this motor are significant, as are the start currents. It is possible to evaluate the potential for energy savings by using the maintenance register data and Eq. (2), as shown in Table 2.

Table 2
Savings in energy

Units	Intermission time (min)	Standard Deviation (min)	Percent Deviation (%)	Leakage volume (m^3)	Leakage flow(l/min)
1	5.3	0.35	6.80	0.62	116.5
2	6.2	0.40	6.50	0.53	84.00
3	4.8	0.33	6.80	0.52	106.70

Groupings on the Table 2, appears as a result of the 50 Hz driver's operational characteristics. Based on this calculation, the amount of global energy that could be saved is 3500 KWh.

This is a theoretical maximum, it might be decreased, for example, by the installation of a makeup pump, however, it holds a very high potential for any conventional industrial setting. The sole immediate effect of this upgrade is the energy savings.

The key benefits for the maintenance are the lower costs, the need for fewer lead pump spare parts, and the higher quality of the oil. As a result, the generating units are very reliable and have a high uptime. Accordingly, it is possible to select equipment suitable for use in the outlined conditions based on the assessed results and manufacturer catalogs.

3.1 Choose a Hydraulic Pump

Use Eq. (1) and Eq. (2) to calculate the units' maximum driving power.

$$\text{Minimum pump displacement}, S_d = \frac{116.5 \times 1000}{3600} = 32.36cm^3$$

$$W_t = \frac{116.5 \times 40}{60} = 7766 \text{ W}$$

The recommended maximum drive power is 10^3 W.

Then new $Q_t = \frac{10^3 \times 10 \times 60}{40} = 150L/min.$

Let's suppose that the maximum leakage flow, 116.5 L/min, from Table 1 is indeed the theoretical flow Qt. Using the formula in Eq. (4), we find that the bare minimum speed for the driver is 3600 RPM, which translates to a displacement of the pump of 32.36 cm^3. Using the same theoretical flow and operating pressure (4.0 MPa), Eq. (2) yields a minimum driving power of 7.7 kW. The standard specifies a reference flow that is double the amount needed for the hydraulic mechanism. However, since the output from unit 2 is not entirely representative, it is recommended that the maximum driver power be capped at 10 kW. To accomplish the goal of creating a compact and cost-effective system, this is essential. Consequently, at the same pressure, the maximum theoretical flow is 150 L/min, according to Eq. (2).

The gear type rotor pump will be used because it was found to be the most suitable option after searching through manufacturer catalogues for the appropriate machinery. The gear pump is a viable solution because of its user-friendliness, maintenance simplicity, efficiency, cavitation resistance, and small size. The Parker Hannifin catalogue was consulted as a second credible source of technical data; It describes a pump with an output flow of 126.97 L/min and a constant displacement of 36.50 cm^3. The characteristic curves of the gear pump are shown in Figure 3 using catalogue data. The H90 gear pump was chosen for this project because it can deliver oil at pressures up to 10.3 MPa [32].

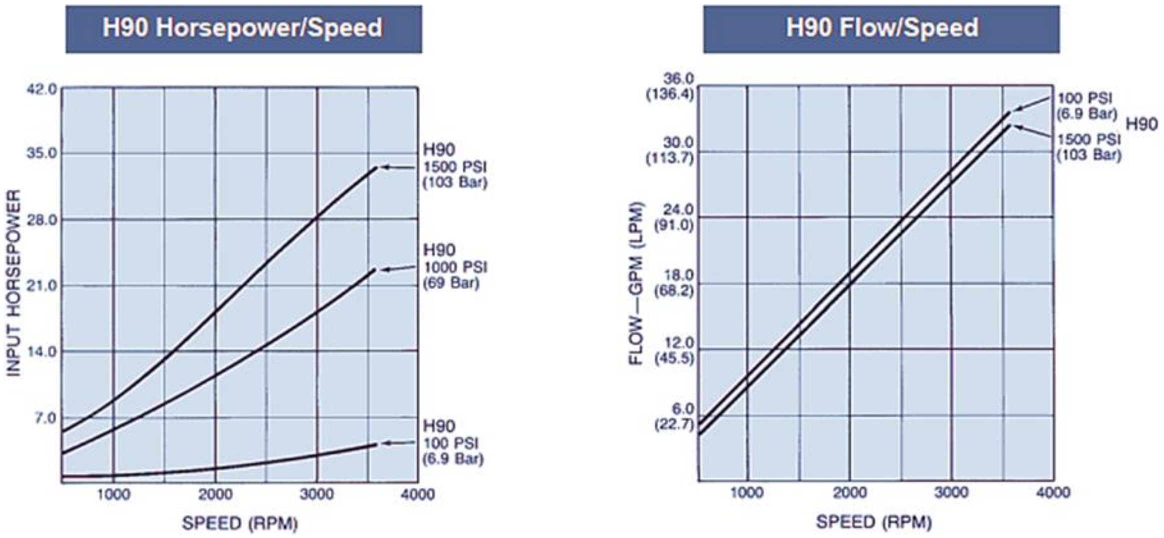


Fig. 3. Gear pump characteristic curves

Figure 3, which depicts how input power increases with flow, allows one to compare theoretical and actual power for pressurization at 4 MPa, which is close to the operational pressure for the speed governor specified in the catalogue. The efficiency of the pump can be calculated by comparing the theoretical and actual power ratios. In keeping with what is depicted in Figure 3, about 89% is the average value for the efficiency that can be attained.

By comparing the flow shown in the catalogue with the flow, the amount of internal leakage in this pump can be estimated at the specified pressure and speed. The pump's leakage was empirically tested using the equipment, and it follows a curve that is affected by the discharge pressure and the rotational speed of the pump's motor. Limitations in accurately mapping the driver's behavior arise from the fact that this value is pressure-dependent. If the pump's operating pressure is held constant, the driver torque will also remain constant, and the power output will be proportional to the pump's rotational speed.

Table 3 displays the average leakage value over a sustained period of time, the standard flow reference, the power required to run the pump at its nominal speed, and the average efficiency evaluated above. Those red numbers indicate the range of units for which it is impossible to adhere to the standard standards for hydraulic design. However, even if the design's premise is flawed due to these occurrences, the number of pumping cycles will be reduced and, in some cases, entirely eliminated. For the pump's inlet flow pressure to remain at or more than 127 mmHg at 3600 RPM and 254 mmHg at 1800 RPM, the manufacturer specifies a minimum suction height that must be adhered to.

Table 3
Parameters for running selected pumps from each generating unit

Unit	Main flow (L/min)	Standard flow (L/min)	Power (KW)	Speed of driver (RPM)
1	116.5	233.03	16.15	3440
2	84.00	167.80	11.22	2960
3	106.7	224.88	16.15	3440

These findings suggest that a low-power driver can be used with these pumps to get the needed flow at the system pressure. Additionally, the efficiency is reasonable, and altering the pump driver's speed allows one to regulate the delivered flow rate. These improvements to the hydraulic circuit lessen the burden on the facility's electrical system by extending the life of the primary pressurization pumps and decreasing the frequency of required maintenance. By modifying this pump, it may be possible to accomplish those objectives by extending or doing away with the pressurization intermission period.

3.2 Verification of the Study

The present model is linked to the studies of Mahato and Ghoshal [5] and Gustafsson [33] to validate and evaluate the current results and to fill the void left by the lack of a suitable experimental study similar to the present model of improving production efficiency over mechanical governors in the hydropower station. The present study's results were compared with those of Gustafsson [33] and Mahato and Ghoshal [5]. Here, we apply the same constraints to the study's findings. For this purpose, we can say that there is substantial agreement between the two sets of data. This shows that the outcomes of the current investigation are as predicted. In addition to the experiential learning course and its associated records.

4. Conclusions

These findings indicate that it may be possible to greatly reduce power consumption, resulting in a more effective system, and lengthen the heat exchangers' recirculation duration to prevent oil overheating. The speed governor for equipment that makes energy depends on hydraulic systems to create actuation power.

According to Table 2, the power station has the ability to save energy across all units. Whereas the maximum load power consumption was 5414 KWh before the study, it has been reduced to 1914 KWh after the study, for a savings ratio of 54.6%.

5. Prospective Studies

Research the usage of the device for soft-starting motors, speed drive apparatus throughout the loading and unloading process for all motors that are used to drive the governor pump for start-stop. This component temporarily reduces the powertrain's load and torque. when used with an AC electrical motor. Reduce transient voltage drops that can affect other loads, prevent pressure spikes, start-up smoothly, and ensure power supply stability.

The drainage pump system, which was used to stop the guiding vane and gate servomotors from leaking a lot of oil into the main tank, was looked at, and if needed, its design was changed.

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