



**HAL**  
open science

# Optimal Efficiency Controller Design of Pumping Systems

Samir Nassiri, Moussa Labbadi, Chakib Chatri, Mohamed Cherkaoui

► **To cite this version:**

Samir Nassiri, Moussa Labbadi, Chakib Chatri, Mohamed Cherkaoui. Optimal Efficiency Controller Design of Pumping Systems. 2024. hal-04561955

**HAL Id: hal-04561955**

**<https://amu.hal.science/hal-04561955>**

Preprint submitted on 3 May 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Optimal Efficiency Controller Design of Pumping Systems

Samir Nassiri, Moussa Labbadi, Chakib Chatri, and Mohamed Cherkaoui

**Abstract**—This work presents a strategy to design an optimal efficiency controller for a complete water pumping system, aiming for both high dynamic performance and high efficiency. The novelty of the developed model is based on an optimisation strategy where a compromise is made between minimizing the electric motor power losses and accurate adjustment of flow rate by balancing efficiency and reliability through adjusting the operation point of the pump. To accomplish this goal, this paper presents the design of an optimal controller which integrates both the Minimum Electric Loss (MEL) control strategy, and the Linear Quadratic Regulator (LQR), augmented by adding integral action and tuned using an adaptive Genetic Algorithm optimization tool (GA). In order to further verify the accuracy of the proposed technique, three performance indices as compared to the conventional PI controller in terms of control input and disturbance rejection. Finally, simulation tests performed show that the proposed optimal can effectively improve the adaptability and flexibility of the water pumping system to several complex working conditions and also has the ability to reduce energy conversion efficiency, leading to a significant impact on energy savings.

**Index Terms**—optimal controller, pump, valve.

## I. INTRODUCTION

Pumps powered by asynchronous three-phase electric motors represent a significant part of the industry, being used for liquid transfer and delivery. Pumping systems, especially centrifugal pumps, consume roughly 30% of the energy requirements in the industrial sector. Such a motor-pump system converts the electrical power into the pressure energy of a liquid that comes from the volute casing. In most cases, this form occurs in the motor windings, motor bearing frame, stuffing boxes, mechanical seals, friction, throttle valve, and other losses in the volute, pipeline, and impeller [1]. To ensure high efficiency and to decrease the energy consumption of the pump system, including a centrifugal pump and an induction motor (IM), it is necessary to minimize power losses in the overall pump system. Special attention is paid to the important role of variable speed drives (VSD) [2]. The optimization of variable-speed pumps to achieve maximum efficiency of the pump system is a challenging due to the constraints of the system, evolutionary algorithms have been widely concerned by researchers to solve the optimization problem such as, Genetic algorithms, simulated annealing, particle swarm optimization, ant colony optimization; fuzzy optimization, golden section search (GSS),

neural-network-based methods, Multi-objective optimization, convex problems, and multidisciplinary optimization. Most of these methods are emerging as certain characteristics of neurobiological systems, swarm of insects, and molecular for the solution of complex engineering problems [3]. A review of different efficiency improvement schemes in this regard is presented in [4]. Besides, Using evolutionary algorithms can decrease the robustness of the solution, especially under the effects of uncertainty. Therefore, for more robust, stability, and good fastness, control are necessary to minimize instability, guarantee a fast response, increase disturbance rejection performance and reduce the operating cost [5]. Many techniques have been designed, such as intelligent fuzzy logic control, Hybrid control techniques, neuro-fuzzy technique, discrete-time neural inverse optimal control, sliding mode controller, model predictive torque control, fractional order terminal SMC, and optimal control. Over the last few years, researchers have been exploring the optimal control, especially the linear quadratic regulator (LQR) which is one of the most important issue of modern Control Theory [6]. The LQR technique are becoming increasingly popular in an industrial process control, which has simple mathematical processes, easy implementation without prior knowledge, and can achieve closed loop optimal control with the linear state feedback or output feedback. Many researchers use of advanced methods in determining the weight matrices. However, they faced difficulties and do not guarantee the expected performance. To surmount these difficulties and for enhancing the control performance, in most recent studies, the genetic algorithm GA approach is added to the LQR for selecting the optimal Q and R matrices, since it is a practical alternative to obtain the control parameters, and provide a powerful technique for tuning optimized parameter method. On the other hand, the optimal operating power efficiency cannot be guaranteed only by varying the speed of the pump. Reducing operating losses in an induction motor with optimal control is also required to achieve electrical energy savings for hydraulic systems [7]. A number of research studies have been conducted to investigate how to minimize the energy consumption of IM. A minimum electric loss model (MEL) was developed in [8]. The main contributions to this paper are as follows: We design optimal efficiency controller system integrates MEL condition and LQR augmented by adding integral action and tuning by GA; We present the mixing two-mode control valve and the speed control aiming to get a suitable operating mode by balancing efficiency and reliability.

S Nassiri, C Chatri, and M Cherkaoui are with Engineering for Smart and Sustainable Systems Research Center, Mohammadia School of Engineers, Mohammed V University in Rabat, Morocco.(e-mail: chakibchatri@research.emi.ac.ma; ouassaid@emi.ac.ma; yassineelhouch@research.emi.ac.ma).

M. Labbadi is with the Aix-Marseille University, LIS UMR CNRS 7020, Marseille, France, (e-mail: moussa.labbadi@lis-lab.fr).

## II. SYSTEM MODEL

### A. Modeling of the Asynchronous Electrical Motor

The mathematical modelling and analysis of the dynamic performance of a squirrel-cage induction motor can be obtained by using  $(d-q)$  synchronous rotating reference frame with the rotor flux space vector [7]. The total power losses of the induction machine are divided into winding losses and core losses, which are fully explained in [5]. On the basis of [8], we applied the condition for the field orientation  $\psi_{sd} = \psi_s, \psi_{sq} = 0$ , the total motor losses can be described in terms of d- and q-axis current components as follows:

$$P_{Loss} = \frac{3}{2} \left( R_s + R_r \frac{L_m^2}{L_r^2} \right) (i_{ds}^2 + i_{qs}^2) - 3R_r \frac{L_m}{L_r^2} \psi_{rd} i_{ds} + \frac{3}{2} \left( \frac{R_r}{L_r^2} + n_p^2 \omega_M^2 \frac{L_m^2}{R_m L_r^2} \right) \psi_{rd}^2 \quad (1)$$

where  $c_{Fe}$  and  $c_{str}$  are the stray and iron loss coefficients, respectively. The decoupled control of the d- and q-axis stator currents gives the developed electromagnetic torque:

$$T_e = \frac{3}{2} p \frac{L_m^2}{L_r} i_{sq} i_{sd}. \quad (2)$$

The main specifications of the components used in this investigation are mentioned in Table I.

TABLE I  
SPECIFICATIONS OF THE COMPONENTS.

Component	Specifications
Electrical Motor	Max. power of the motor: 1.1 KW. Nominal speed 2800 rpm; $L_r = 0.029$ ; $R_r = 5.313$ ; $L_s = 0.029$ ; $R_s = 6.959$ ; $L_m = 0.6786$ ; $J = 0.6786$ ; $b = 0.00114$ .
Centrifugal Pump	Nominal speed 1770 rpm, pump's parameters all defined in MATLAB by approximating polynomial
Pipeline	Nominal diameter: 0.0381 m (1.5 in). Length: 10 m
Control Valve	Proportional Valve Nominal diameter: 0.0381 m

### B. Modeling of the Centrifugal Pump

The centrifugal pump is connected to a pipeline, which transfers water from a feeder tank to an upper reservoir. A flow rate regulation is generated by a throttling valve, which is located at the inlet of the pump and is used to generate an external perturbation to the control system [2]. The system characteristics of a centrifugal pump can be approximated by the polynomial of pressure differential  $H$  which is created by impeller rotating speed:

$$H = (a\omega_r^2 + bQ\omega_r + cQ^2) = k_1\omega_r^2, \quad (3)$$

where  $Q$ ,  $a_1$ ,  $a_2$ , and  $a_3$  are output flow rate and polynomial coefficients for pump which can be approximated with plotting and fitting (3). The centrifugal pump opposes a resistant torque proportional to the square of angular velocity of the motor (the rotor speed) and flow.

$$T_p = k_p Q \omega_r \quad (4)$$

where  $k_p$  is the centrifugal pump constant which depends on pump nominal data.

### C. Modeling of the Pipe System and Valve

The resistance of the piping system must be calculated to find the operating pressure head of the system. The expression of the pressure loss generated in pipelines are defined by means of the Darcy-Weisbach formula [3], [?], [6].

$$H_{losses} = k_2 Q^2 \quad (5)$$

where  $k_2$  is the constant of losses which can be obtained by plotting and fitting the losses generated in the pipeline (2). The flow through the control-valve in the hydraulic system can be calculated by means of [5]

$$Q = k_{v0} A(x) \sqrt{\frac{\Delta p_v}{\rho}} \quad (6)$$

where  $k_{v0}$  is the constants of the valve determined by the valve manufacturers,  $\Delta p_v$  is the pressure difference across the valve and  $A(x)$  is usually a nonlinear function as a function of the stroke of valve  $x$  that expresses the change in the cross-section of the valve. Replacing (3) and (5) into (6), the  $Q$  flow rate is given by:

$$Q = \sqrt{\frac{k_3 A^2}{[1 + k_4 A^2]} \omega_r}, \quad (7)$$

where:  $k_3 = \frac{k_1 k_{v0}^2}{10.2}$ , and  $k_4 = \frac{k_2 k_{v0}^2}{10.2}$ . From Eq (9), it can be concluded that the  $Q$  flow rate depend on the relative value of the control valve stroke  $x$  and the rotor speed.

## III. CONTROLLER DESIGN AND ANALYSIS

The proposed technique aims to design an optimal controller to achieve the highest efficiency of the pumping system. The first part is to minimize the amount of electrical input power under the hydraulic system constraint. For this reason, and for maintaining pressure  $H$  and flow  $Q$  to be constant (the mechanical power is constant), it is possible to reduce the loss of machine, by minimizing the value of the electric losses, in this case considering that both the electromagnetic torque  $T_e$  and  $\omega_r$  are constant with respect to  $i_{sd}$  current. The electric loss minimization condition is given by [7]

$$\frac{\partial P_{Loss}}{\partial i_{sd}} \Big|_{\omega_r=const.} = 0. \quad (8)$$

and the electromagnetic torque with respect to  $i_{sd}$  current.

$$\frac{\partial T_e}{\partial i_{sd}} \Big|_{\omega_r=const.} = 0. \quad (9)$$

The MEL condition is obtained by using the above conditions, in this case, substituting (1) into (9), and using (10), we obtain:

$$i_{sd_{opt}} = G_d \Big| i_{sq_{opt}} \Big| \sqrt{\frac{1 + T_a^2 \omega_e^2}{1 + T_b^2 \omega_e^2}}, \quad (10)$$

where  $G_d = \sqrt{1 + \frac{R_r L_m^2}{R_s L_r^2}}$ ,  $T_a = L_m \sqrt{\frac{c_{Fe}(L_r - L_m)^2 + c_{str}}{3(R_s L_r^2 + R_r L_m^2)}}$ , and  $T_b = L_m \sqrt{\frac{c_{Fe}}{3R_s}}$ . From Eq (11), it's clear that the optimal reference value of the rotor flux in field-oriented (d,q) system is guaranteed by the direct stator current  $i_{sd_{opt}}$ , and it can be concluded that the factor  $T_b^2 \omega_e^2$  can decrease the iron loss by reducing the field current.

The second part is based on the calculation of the net mechanical torque of the induction motor, which is a sum of torques about the common axis of the motor and the water

pump, a dynamic nonlinear model of the moto-pump and pipeline system is written as follows:

$$J \frac{d\omega_r}{dt} = \frac{3}{2} p \frac{L_m^2}{L_r} i_{sq} i_{sd} - k_p Q \omega_r - b \omega_r. \quad (11)$$

The equilibrium operating point of the motor-pump system is obtained when

$$\frac{d\omega_r}{dt} = 0, \quad (12)$$

and the MEL condition that determines the optimal d-axis component is given by

$$i_{sd_{opt}} = \sqrt{G_q G_d} \left[ \frac{1 + T_a^2 \omega_e^2}{1 + T_b^2 \omega_e^2} \right]^{1/4} \sqrt{\omega_r}, \quad (13)$$

and we conclude optimal q-axis component.

$$i_{sq_{opt}} = \sqrt{\frac{G_q \omega_r}{G_d} \left[ \frac{1 + T_b^2 \omega_e^2}{1 + T_a^2 \omega_e^2} \right]^{1/4}}. \quad (14)$$

The third part is based on the linearization of the dynamic model of the pumping system around the equilibrium operating point in state space. The state equations expressed as non-linear differential equations  $\dot{X} = F(X, U, D)$ , where  $\dot{X} = AX + BU + ED$ , and  $Y = CX$ ; with  $X, U, Y$  and  $D$  refer to the state vector of the the dynamic model of pumping system, the input, control output, and disturbance vector, respectively, and  $A, B, C, E$  are the linear system matrix,

$$A = \frac{\partial F}{\partial X} |_{x_d}, B = \frac{\partial F}{\partial U} |_{u_d} \text{ and } E = \frac{\partial F}{\partial D} |_{D_d}. \quad (15)$$

and

$$X = \left[ i_{sq} \quad i_{sd} \quad \psi_{rd} \quad \omega_r \quad \int i_{sq} \quad \int i_{sd} \right]^T, \\ U = [u_{sd} \quad u_{sq}]^T, \\ Y = [\omega_r \quad i_{sd}]^T, \quad D = [x]^T.$$

where the throttle valve is a perturbation induced in the pipeline.

The next step is to construct an optimal regulator to achieve the best control performance for the system.

In fact, an LQR linear regulator has the best control performance among various linear controllers [9]. The LQR regulator is a state-feedback control system that computes the optimal feedback gain matrix based on the desired location of poles, which is used to minimize the quadratic cost function (J):

$$J = \int_0^{\infty} \left( X_e^T Q X_e + u_c^T R u_c \right) dt; \quad (16)$$

where  $Q$  and  $R$  represent the weighting matrix for state  $X(t)$  and control input  $u(t)$  respectively, which are set as positive. The proper selection of matrices  $Q$  and  $R$  define the optimal matrix gain  $K$  of the closed loop optimal control law

$$u_c = -K X_e; \quad (17)$$

where  $X_e = X_{ref} - X$ , and  $K = R^{-1} B^T P$  with  $P$  obtained by solving the algebraic Riccati equation in the steady state

$$A^T P + P A - P B R^{-1} B^T P + Q = 0. \quad (18)$$

A command in Matlab for LQR control system design is used once the model of the pumping system has been linearized, and the matrix values of its state space representation have been determined.

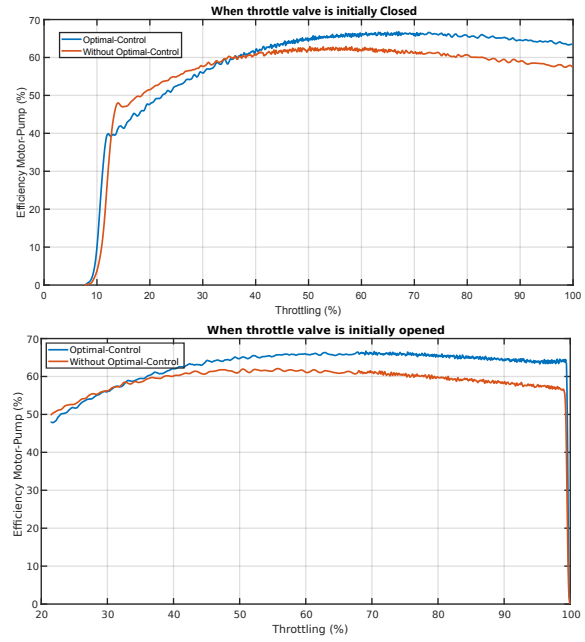


Fig. 1. Global efficiency of system with adjusting the stroke of the throttle valve.

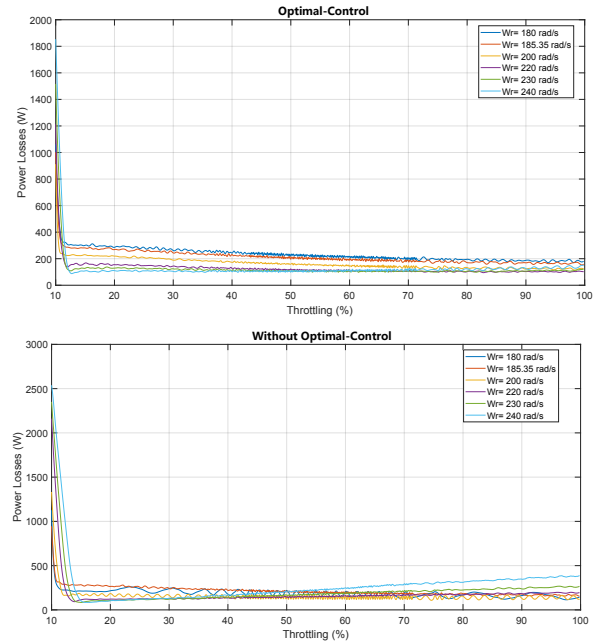


Fig. 2. Electric loss of the motor with adjusting the stroke of the throttle valve and rotational speed.

In order to find the maximum possible efficiency, the Genetic Algorithm (GA) in the context of the LQR controller can be implemented to find new optimal controller gains by optimal tuning of the weight  $Q$  and  $R$  matrices to get satisfactory closed loop poles via the LQR controller. The genetic algorithm (GA), described by John Holland in the 1970s, is a new metaheuristic algorithm inspired by

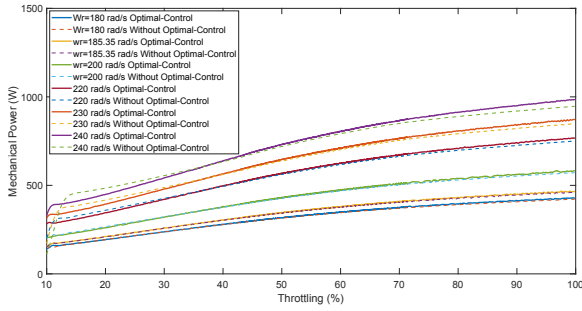


Fig. 3. Mechanical power of the motor with adjusting the stroke of the throttle valve and rotational speed.

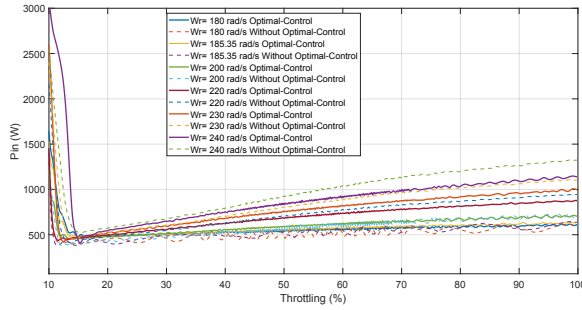


Fig. 4. Input Power of the motor with adjusting the stroke of the throttle valve and rotational speed.

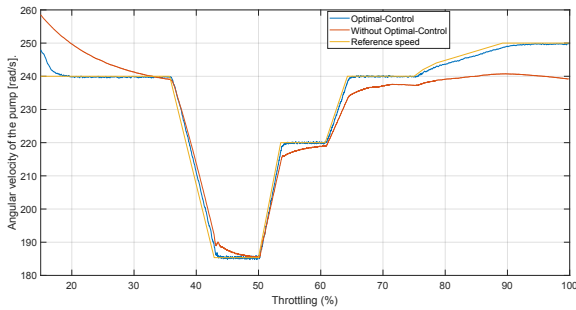


Fig. 5. Time response of speed response of different control techniques with adjusting the stroke of the throttle valve.

the biological evolution process. These biologically inspired algorithms are regarded as the global optimisation technique because they have a very powerful potential in solving real and practical applications in control systems. [5].

#### IV. SIMULATION RESULTS AND DISCUSSION

The whole control system applies adaptive genetic algorithms and is performed by using MATLAB® and SIMULINK® workspace. The simulation studies have been carried out on a system consisting of an asynchronous electric motor connected to the power grid using PWM converters with the space vector control technique, centrifugal pump, ball-valve, and pipeline with two tanks (suction and delivery) and in two different cases: (a) with a non-

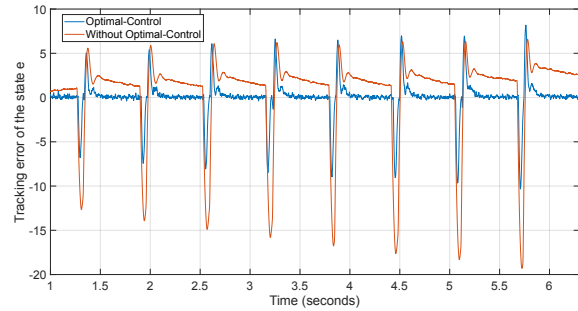


Fig. 6. Time response of the responses of error of the state using sudden closing of the throttle valve.

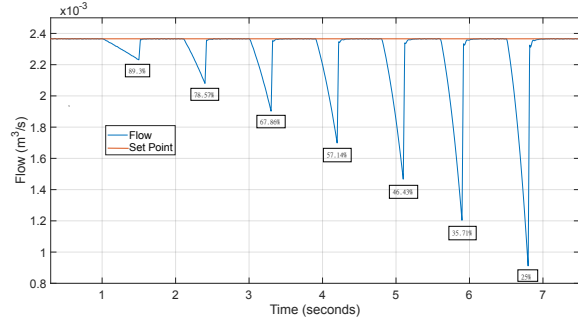


Fig. 7. Time response of flow rate of optimal control technique using sudden closing of the throttle valve.

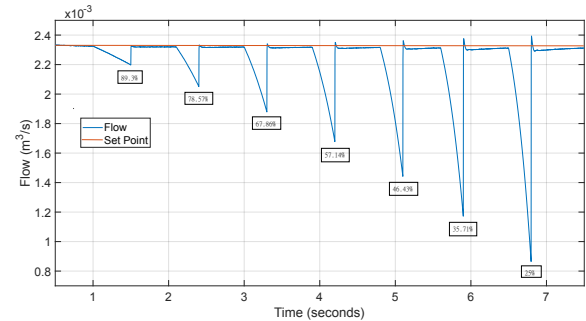


Fig. 8. Time response of flow rate of without optimal control technique using sudden closing of the throttle valve.

optimized controller (PI), and (b) with an optimized controller (MEL-LQR-GA). The parameters of the asynchronous electric motors, centrifugal pump, pipeline, and valve system are mentioned in Table 1. As explained in the previous section, the adaptive Genetic Algorithm optimization tool in MATLAB can find the state optimal weighting matrix, Q, and the input optimal weighting matrix, R, to achieve satisfactory closed loop poles via the LQR controller and the optimal gains, K and Kg, for the maximum possible global efficiency of the motor-pump system. The results from the GA program are calculated for about 200 generations. In the second phase, the performance of the MEL-LQR-GA is tested in the presence of external disturbance. The

TABLE II  
OPTIMIZED RESULTS (MEL-LQR-GA)

$\omega$ (rad/s)	$\eta(\%)$ Motor	$\eta(\%)$ Pump	$\eta(\%)$ Motor-Pump	Power Losses (W)	Q ( $10^{-4}$ m <sup>3</sup> /s)	H (m)	Valve Opening (%)
240	87.88	78.49	69	105.7	17.68	35	55.43
230	87.70	78.09	68.50	105.9	17.57	31.76	58.11
220	86.43	76.84	66.43	106.20	18.81	27.6	68.17
200	79.78	75.52	60.28	131.1	18.07	22.19	74.18
185.35	71.81	74.18	53.31	169.1	17.57	18.48	80.25
180	69.55	72.48	50.33	181.5	18.38	16.62	91.18

TABLE III  
NON-OPTIMIZED RESULTS

$\omega$ (rad/s)	$\eta(\%)$ Motor	$\eta(\%)$ Pump	$\eta(\%)$ Motor-Pump	Power Losses (W)	Q ( $10^{-4}$ m <sup>3</sup> /s)	H (m)	Valve Opening (%)
240	79.86	78.29	62.52	162.4	13.81	37.26	41.2
230	79.51	78.45	62.35	165	15.14	33.16	48.55
220	79.89	78.03	62.27	150.1	16.14	29.4	55.89
200	79.44	75.73	60.21	166.7	17.81	22.34	74.18
185.35	71.76	74.09	53.13	170.6	17.69	18.49	83.1
180	65.19	75.48	49.20	200	15.59	18.48	70.71

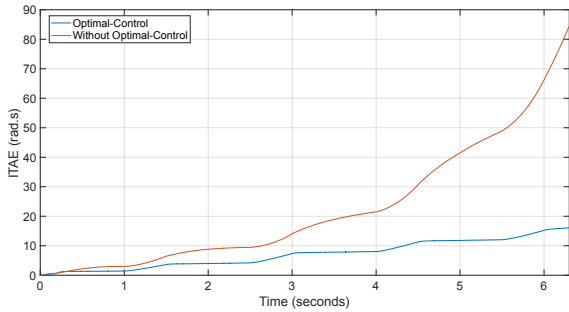


Fig. 9. Integral of time multiplied by absolute error using sudden closing of the throttle valve.

performance of the designed control can be assessed through integral of time multiplied by absolute speed error (ITAE). The Fig. 1 shows a comparison between the optimized and non-optimized overall efficiency at a reference speed of 220 rad/s, when throttle valve is initially Closed or initially opened. It can be observed that the system global efficiency is improved by the proposed technique controller, reaching a 7.49% increase when the throttle valve stroke is opened from 38% to 100%.

Fig. 2 shows the power losses of the proposed controller in comparison with the conventional PI controller at different values of rotor speed with adjusting the stroke of the throttle valve. In the case when the throttle valve stroke is opened from 38% to 100%, the loss of the proposed control strategy is lower than the conventional PI.

The mechanical power delivered to the pump shaft for different values of rotor speed with adjusting the stroke of the throttle valve can be obtained from the curves presented in Fig. 3. As shown in the figure, the required mechanical power of the proposed controller significantly increases compared to the conventional PI when the throttle valve stroke is opened from 38% to 100%. Based on these results, it is

clear that figs. 2, and 3 prove the utility of the optimization, which shows that the optimized control had superiority over the non-optimized control when adjusting the stroke of the throttle valve and the angular speed. It can be observed that there is a considerable reduction in the electric loss of the motor and an increase in the mechanical power at the pump shaft.

Consequently, the optimized control also creates the flow rate and minimizes the input power at different values of percentage valve stroke and different values of rotor speed compared to the non-optimized control, as can be seen in Figs. 4.

Fig. 5, shows the resulting performance of the proposed optimal control under the effect of variable rotational velocities and throttle valve stroke. A variable reference speed decreased from 240 to 185.35 rad/s and then increased from 185.35 to 250 rad/s. For some certain set points and when the rotational velocities and throttle valve stroke change, the non-linearity of the controlled variables by PI are changed, unlike our proposed controlled. Therefore, we conclude that the proposed control scheme improves flexibility against variable-speed and throttling valves compared to the non-optimized control. In addition, Tables I-II recapitulate the simulation results of the water pumping system for variable rotational speed with the stroke of the throttle valve in terms of the efficiency, power losses, flow rate, and head of the optimized and non-optimized water pumping systems. As can be seen, when the two controls are set at 240 rad/s with variation of stroke valve, a considerable reduction in power losses is achieved, reaching a 34,914% reduction, and consequently, the efficiency of the motor is increased by 10,043% and the flow rate is increased by 28,023% in this case. From Tables I-II, it can be observed that when the speed of the motor is set at  $\omega_0 = 230r/s$  with the stroke of the throttle valve for an optimized controller at 58.11%, the efficiency of the pumping is 78.09%, compared

with 78.45% for the non-optimized case of 48.55%. The results demonstrated that adjusting the operation point of the pump by regulating both the stroke of the throttle valve and the variable-speed drive offers a suitable operating mode by balancing efficiency and reliability. It is noticed that the table I indicate the maximum possible efficiency of the pumping is 78.49%, the squirrel-cage machine is 87.88% and the whole motor-pump system is 69% when the stroke of the throttle valve at 55.43% with speed  $\omega_0 = 240r/s$ . This is the maximum possible efficiency that can be obtained with the gains found with the adaptive genetic algorithm. According to the findings, adjusting both the speed and the valve has a significant impact on power losses and the operating region, which can be expanded.

Figs. 6, show the comparison of the error of the state  $e$ , under the influence of the perturbation induced in the pipeline by suddenly setting the throttle valve at a stroke from 89.3% to 25%. It can be observed that the proposed control strategy regulates the error of the state  $e$  after the disturbance with a settling time of error of 0.3, compared with 1.3 for non-optimized control, as shown in Fig. 6.

In Figs. 7 and 8, show the flow rates of the optimized and non-optimized control respectively under the influence of the perturbation induced in the pipeline by suddenly setting the throttle valve at a stroke from 89.3% to 25%. The flow rate returns to the desired value in approximately 0.6 seconds compared with 0.9 seconds for non-optimized after the perturbation of a 89.3% sudden closing of the throttle valve, 0.4 seconds compared with 0.6 seconds for non-optimized in the case of 78.57% sudden closing, 0.377 seconds compared with 0.75 seconds for non-optimized in the case of 67.86% sudden closing, 0.366 seconds compared with 0.74 second for non-optimized in case of 57.14% sudden closing, 0.363 seconds compared with 0.76 seconds for non-optimized in case of 46.43% sudden closing, 0.358 seconds compared with 0.85 seconds for non-optimized in case of 35.71% sudden closing, and 0.356 seconds compared with 0.98 seconds for non-optimized in case of 25% sudden closing.

The performance indices ITAE of the two candidate controls for different values of percentage valve stroke and under the influence of the perturbation induced in the pipeline by suddenly setting the throttle valve are presented in Figs 9. The comparison shows the proposed technique is the best candidate since it renders the flattest error profile and the lowest error and can effectively improve the rejection performance of the disturbance when compared with a non-optimized controller, and consequently, the pump-system can be balanced robustly using the proposed technique.

## V. CONCLUSIONS

The paper discusses an optimal efficiency control scheme that is designed and implemented to operate the motor-pump system in the region of best efficiency. We present the mathematical models of hydraulic pump systems, an asynchronous electric motor coupled with a centrifugal pump, a pipeline system, and the flow control valve. The proposed

controller system is implemented by integrating MEL, and LQR augmented by adding integral action and tuned using an adaptive GA optimization tool. The whole control system is simulated in MATLAB® SIMULINK® workspace and the results show that the optimal controller allows, at the same time, the maximization of the overall efficiency and stabilization of the discharge flow rate for every operation point of the pumping system, and under a disturbance caused by a throttle valve acting on the pipeline. The operating efficiency of the pump and providing the minimum electric loss of the IM depends not only on the adjustment of the rotational speed but also on both variations of the pump rotational speed and valve regulation. In the event that the system has to move to a new operating point, the new steady state conditions appear and the two optimal controllers (MEL and LQR) can follow the variation of pump rotational speed and valve regulation. They will cooperate to find the new optimal operating point at which both the minimum electric losses of the induction motor and the accurate flow rate are attained. Thus, maximum efficiency of the whole motor-pump system is achieved. Finally, to validate the performance and effectiveness of the proposed control scheme, a comparative analysis with the conventional PI controller can be assessed based on the performance indices of ITAE. The comparative results show that the proposed controller is more beneficial from the dynamic stability, and transient response of the motor-pump system in the presence of a perturbation point of view than the conventional PI. It is concluded that optimal controller are especially helpful for improvement of pumping system's efficiency and reliability.

## REFERENCES

- [1] Samir Nassiri, Moussa Labbadi, Mohamed Cherkaoui "Optimal Integral Super-Twisting Sliding-Mode Control for high efficiency of Pumping Systems", 14th IFAC Workshop on Adaptive and Learning Control Systems ALCOS 2022.
- [2] Cristian F. Jaimes Saavedra, Sebastian Roa Prada, Jessica G. Maradey Lázaro, "Modeling And Optimal Control of A Variable -Speed Centrifugal Pump With A Pipeline", IMECE2016-67992.
- [3] Athanasios Mesemanolis, Christos Mademlis, Iordanis Kioskeridis, "Optimal Efficiency Control Strategy in Wind Energy Conversion System With Induction Generator", IEEE (2013) 2168-6777.
- [4] François Malrait, Al Kassem Jebai, Kamal Ejjabraoui, "Power Conversion Optimization for Hydraulic Systems Controlled by Variable Speed Drives", Elsevier Ltd. (2017) 0959-1524.
- [5] Levon Gevorkov, Anton Rassölkin, Ants Kallaste and Toomas Vaimann, "Simulation Study of Mixed Pressure and Flow Control Systems for Optimal Operation of Centrifugal Pumping Plants", Electrical, Control and Communication Engineering (2018) ISSN 2255-9159.
- [6] Levon Gevorkov, Anton Rassölkin, Ants Kallaste and Toomas Vaimann, "Simulation Study of A Centrifugal Pumping Plant's Power Consumption At Throttling And Speed Control", 58th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) (2017).
- [7] M.I. Jahmeerbacus, "Flow Rate Regulation of A Variable Speed Driven Pumping System Using Fuzzy Logic ", 4th International Conference on Electric Power and Energy Conversion Systems (EPECS) (2015) IEEE.
- [8] Xiwen Guo, Yuliang Wu, Guoli Li, Chao Lu, "Dynamic Simulation of an Induction-Motor Centrifugal-Pump System under Variable Speed Conditions", Elktrotehniški Vestnik 84(3): 125-132, (2017).
- [9] Sheng-Ming Yang, and Feng-Chieh Lin, "Loss-Minimization Control of Vector-Controlled Induction Motor Drives", Journal of the Chinese Institute of Engineers, 26:1, 37-45,(2003).