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Comparision of MPC and PID Controls of Sirnak Water Supply Network System

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ABSTRACT

This paper determines the application of a model predictive control (MPC) technique to improve the behavior of the water network supply system, to maintain stable operation of the water flow rate, and reduce the operational cost by manipulating the pump speed. The MPC algorithm is one of the most common automatic control system that has got a wide spread application in process industry. MPC is especially suitable for controlling these types of systems. MATLAB Packaged Program is utilized in the water supply system in Sirnak-Turkey. In this study has been a single input single output linear model of a water supply system considered and Comparised of controls with MPC and PID of water supply system in Sirnak-Turkey.

Simulations of MPC Control algorithms for coating process have been made and the results of these simulations were observed. There is a comparison of PID Controller and Generalized Predictive Controller results and there are comments about this comparison in these studies. The simulations and calculations of the algorithms are done in MATLAB Packaged Program Environment. An increasing demand for water due to population growth, industrial development and improvement of economic require management of water transfer and improve operation of water supply systems. The results show that the MPC technique gives improved performance over the PID control technique, moreover, the MPC structure can be modified to handle the constraints applied on the system.

Keywords: (MPC) Model Predictive Control; PID; Matlab; **C**onstraints; Water supply system.

I. INTRODUCTION

The optimal use of such water supply networks seems to be the best solution for the present and thus it is necessary to carefully manage water transfer [1, 2]. Most of the research in the field of water distribution has concerned with the optimal design of new networks [3], the main topic of this research has been mainly focused on the design of optimized configurations for pipe interconnected reservoirs or concentrated on the scheduling of pumps, however, the energetic efficiency will be sacrificed when the pumps operate under a variable load and hence under non-optimized conditions. [4,5] The optimized operation of this kind of system usually results in a control strategy determination problem for the active elements from measuring the monitoring variable so that some performance target is reached (power minimization, pressure limitation to avoid Leakage, etc.).

Some researchers have developed techniques for the operational optimization of existing supply networks [6, 7]. The objective of this research is the contribution in controlling a water supply network systems using power full control algorithm such as the model predictive control (MPC) algorithm. Mohammed and Abdulrahman studied a MPC technique to improve the behavior of the water network supply system, to maintain stable operation of the water flow rate, and reduce the operational cost by manipulating the pump speed.

The results of these studies are show that the MPC technique gives improved performance over the PID control technique, moreover, the MPC structure can be modified to handle the constraints applied on the system [1].

The MPC algorithm is an alternative to the conventional PID and other advance control algorithm such in [2, 3] as the H_∞ control algorithm used by Ekar and Kara [4-7] for its superiority and robustness for controlling processes of multi-inputs multi-outputs and subjected to constraints. The idea of the MPC emerged in 1965, where Dawkins and Briggs [8] used weighting function as a system description for use in optimal control. However, it was rarely used as a controller in control engineering until the advent of digital computers.

There are different MPC algorithms that could be suitable for single and multivariable systems and are successfully applied to real life processes include dynamic matrix control (DMC) 1978 [9], and generalize predictive control (GPC) 1987 more review on these algorithms is given by Mackay etc. [10].

All of these classes of MPC have certain features in common, implementation of receding horizon to solve a finite horizon optimization problem, with differences occurring in the sequence of control implementation and in the underlying formulation of the models and constraints. Some of these MPC methods use non-parametric weighting function models forms during the prediction process, and others use parametric models [11].

Parametric predictive controllers allowed for a more efficient algorithm and making the incorporation of adaptive techniques more feasible, whereas non-parametric predictive controllers are very robust when compared to parametric models, at the cost of computation power. DMC uses non-parametric step response models to generate both the free and forced responses [12-15]. However, GPC uses the impulse response to generate the forced response, parametric controlled auto-regressive and integrated moving average (CARIMA) model to generate the free response. a different number of extensions to the original DMC have been incorporated to deal with constraints, multi-variable interactions and nonlinear systems and a review on the recent advances on MPC algorithm can be found in [16].

II. METHODS AND MATERIAL

2. Water Supply System

Water supply systems are generally composed of a large number of interconnected pipes, reservoirs, pumps, valves, and other hydraulic elements which carry water from retention to demand areas [1, 4]. The hydraulic elements in a supply system may be classified into two categories: active and passive. The active elements are those which can be operated to alter the flow rate of water in specific parts of the system, such as pumps and valves.

The pipes and reservoirs are passive elements, insofar as they receive the effects of the active elements. These elements in the supply systems play important roles in dynamic behavior of the water supply systems. Simulations of the water supply systems have been an indispensable work to understand their behavior to produce a feasible control solution as well as modeling.

The simulations can thus be used to generate deas in order to develop flexible management and design schemes. Consequently, this process may facilitate a better exchange of ideas among representatives of different professions. It also combines technical and financial viewpoints. The first step in simulation and control is to establish a mathematical model for the plant to be controlled. Furthermore, an adequate model is an important step in determining the behavior and producing a well MPC algorithm.

Hydraulic systems generally require complex models. Derivation of control strategies on the basis of the complex models is difficult. For these reasons, the plant model should be chosen to be simple with a minimum number of dominant variables, which, nevertheless, adequately reflect the dynamics of the plant.

The plant can be described by the parameters that characterize its functioning such as the pumps discharges, water heads in the reservoirs, and flow rates through the system .Thus the simulation of the model that represents a water supply system may prove an efficient measure to contribute to the correct transfer of water and to reduce operational cost, as well as to improve the operation.

The active and passive elements are represented by dominant system variables. The main objectives are to ensure the proper operation of a water supply system and to regulate the water flow rates and heads by manipulating the water pumps. By assuming that the water is incompressible and the individual system components are stationary the hydraulic model of the supply system is composed of the following models for every component of the supply system.

2.1. Plant Definition

The water source from Mijin place of Senoba village is 41 km. distance from the Sirnak state in Turkey. Fig 1 shows the general scheme of the water supply system in which there are three pumping stations (PST-1, PST-2, PST-3) and three reservoirs (RS-1, RS-2, RS-3) in the supply system. The supply system is a one-line system, and any water is included or dispersed in the supply system.

3. Pumps

Head developed by n variable-speed pumps running in parallel varies nonlinearly with their speed N rpm and output water flow rate Q_p (t) m^3/s.

$$h_p(N, Q_p) = A_o N^2 + B_o/n\, NQ_p - C_o/n^2\, Q_p \qquad (1)$$

where A_o, B_o, C_o are the constants for a particular pump depending on component characteristics [1, 4]. These constants can also be calculated using appropriate manufacturer’s specifications.

4. Pipes

Consider a pipe section with length l_p (m) and cross-sectional area A_p (m^2) . If the head difference Δh between two ends of the pipe section is considered, the following differential equation is obtained:

$$d\, Q(t) / dt = gAp/lp\, [\, \Delta h(t) - h_{loss}(t)\,] \qquad (2)$$

Where $h_{loss}\,(t)$ parameters the total head loss along the piping section and g parameters the acceleration of gravity. The flow rate and head loss may be given as:

$$h_{loss}(t) = h^o_{loss}(t) + \Delta\, h_{loss}(t)$$
$$Q(t) = Q^o + \Delta\, Q(t) \qquad (3)$$

Table 1. The technical characteristics of the water supply system

Pipe Length (m)	**Man. High (m)**	**Pump Speed (rpm)**	**Flow Rate (m^3/s)**	**Pipe Dia. (m)**	**GravityAcce. (m/s^2)**	**Pipe Sec. (m^2)**	**Reserv. Sec. (m^2)**
lp_1 = 789.05	hs_1=234.5	N_{so} = 945	Q_{so} = 2.25	D = 1.2	g = 9.81	A_p =1.2178	A_t = 525
lp_2 = 2156.34	$hs_{\,2}$=367.3						
lp_3 = 1578.05	hs_3=341.7						
lp_4=3789.40	hs_4=295.8						

Where choosen which steady-state operating point of pump speed is N_{so}= 945 rpm and flow rate is Q_{so} = 2.25 m^3/ s). (.)^o parameters steady-state value and $\Delta h_{loss}\,(t)$ designates the variable head loss caused by the variable water flow rate $\Delta Q\,(t)$. Intercalarily, A_p is circular area of concrete type pipe and A_t is surface area of all resevoirs and D is inner diameter of concrete type pipe.

5. Water Reservoir

When a reservoir discharges under its own head without external pressure, the continuity equation simplifies to:

$$\rho\;\; dh(t)/dt = 1/c\, [\, \rho_i\, Q_i\,(t) - \rho_o\, Q_o\,(t)\,] \qquad (4)$$

Where ρ, ρi, ρo represent the water densities inside the reservoir, water inflow, and out flow, respectively, and these are assumed equal $(\rho=\rho_i=\rho_o)$.$Q_i(t)$ m^3/s and $Q_o(t)$ m^3/s parameters reservoir input and output water flow rates, respectively, c (m^2) parameters the capacity of the reservoir and $h(t)$ (m) is the head in the reservoir [1].

Figure 1 shows scheme of the water supply system in Sirnak. A single input single output linear model of a water supply system considered in this study has been developed for the water supply system shown in figure 3. by Mohammed and Abdulrahman [1].

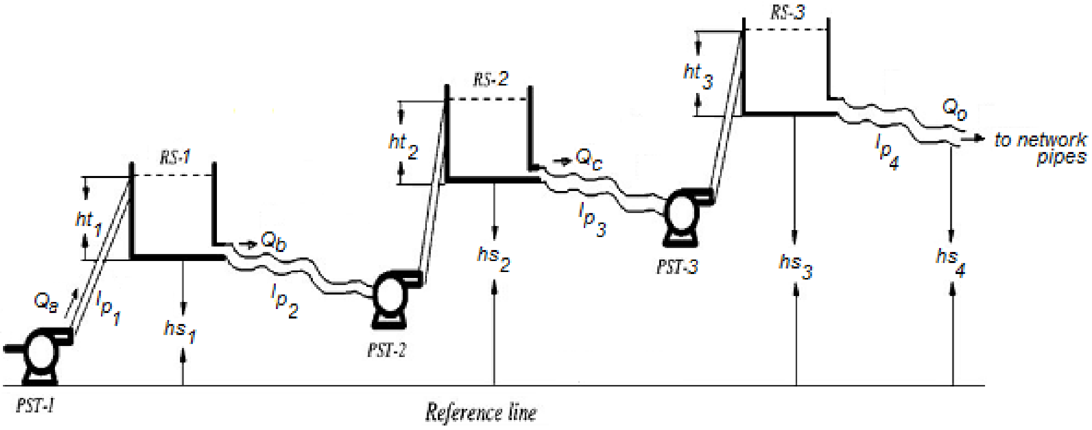

Figure 1: Schemes of the Sirnak water supply system

The input to the system is considered to be the pump speed N rpm and the ouptut of the system is the flow rate from the third reservoir $Q_o(t)$ m^3/s. The numerical data about the water supply system are given in Table 1. The output water flow rate was measured at 1hours intervals in a day, so 24 measurements were taken using a flow meter installed on the real system.

Using the data obtained, the average water flow rate is about Q_o=2.25 m^3/s (8100 m^3/h) and it changes between 8000 m^3/h and 8200 m^3/h . The pump characteristics were obtained from the pump's manufacturer. Head developed by the pump was calculated around the operating point using the characteristic curve as

$$H_p\,(N, Q_p) = 0.0001755\,N^2 + 0.00489\,NQ_p - 2.13\,Q_p^{\,2} \qquad (5)$$

The linear model of the water supply system shown in figure 1 was obtained by linearizing the mentioned system using the Taylor series expansion method around a steady-state operating point (N_{so} = 945 rpm, Q_{so} = 2.25 m^3/s). A detailed study on the system modeling is given by Mohammed and Abdulrahman [1]. The resulting equations (6 - 13) of the system using the above data and operating point in table 1 are as follows:

$$dQ_a/dt = 0.0058\,N - 0.0197\,h_{t1} - 0.4356\,Q_a \qquad (6)$$

$$d\,h_{t1}/dt = 0.0034\,Q_a - 0.0034\,Q_b \qquad (7)$$

$$dQ_b/dt = 0.0041\,h_{t1} - 0.0041\,h_{t2} - 0.0502\,Q_b \qquad (8)$$

$$dh_{t2}/dt = 0.0034\,Q_b - 0.0034\,Q_c \qquad (9)$$

$$dQ_c/dt = 0.0015\,h_{t2} - 0.0015\,h_{t3} - 0.0213\,Q_c \qquad (10)$$

$$dh_{t3}/dt = 0.0034\,Q_c - 0.0034\,Q_o \qquad (11)$$

$$dQ_o/dt = 0.0027\,h_{t3} - 0.0176\,Q_o \qquad (12)$$

$$y = Q_o \qquad (13)$$

This system can be represented in state space matrix form such that the reservoir heads and flow rates can be considered as states.The canonical state space form of the above equations
(6-13) is as follows:

$$\dot{x}\,(t) = A\,x(t) + B\,u(t), \quad y(t) = C\,x(t) \qquad (14)$$

where $x(t)$ is the state matrix and A, B, C are the constant system matrices, $u(t)$ is the system input, and $y(t)$ is the system output. The state matrix $x(t)$, input $u(t)$, and calculated constant matrices A, B, C are as follows:

$x(t)$=[Q_o ht_3 Q_c ht_2 Q_b ht_1 Q_a]^T, B=[0 0 0 0 0 0 0.0058]^T, C=[1 0 0 0 0 0 0], and $u(t)=N$,

$$A = \begin{pmatrix} -0.0176 & 0.0027 & 0 & 0 & 0 & 0 & 0 \\ -0.0034 & 0 & 0.0034 & 0 & 0 & 0 & 0 \\ 0 & -0.0015 & -0.0213 & 0.0015 & 0 & 0 & 0 \\ 0 & 0 & -\ 0.0034 & 0 & 0.0034 & 0 & 0 \\ 0 & 0 & 0 & -0.0041 & -0.0502 & 0.0041 & 0 \\ 0 & 0 & 0 & 0 & -0.0034 & 0 & 0.0034 \\ 0 & 0 & 0 & 0 & 0 & -0.0197 & -0.4356 \end{pmatrix}$$

6. Model Predictive Control

Model Predictive Control (MPC) is commonly used for control of highly stochastic processes where selection of control actions, based on optimization, is desired. The importance of MPC compared with traditional approaches is due to its suitability for large multi-variable systems, handling of constraints placed on system input and output variables, and its relative ease-of-use and applicability. In MPC, current and historical measurements of a process are used to predict its behavior for future time instances. The MPC is supported by commercial tools such as MATLAB (Mathworks 2010a).

It consists of a System Prediction Model and Optimizer. The error between future outputs and target trajectories (i.e., expected customer demand) is sent to the optimizer where optimized control outputs (referred to as manipulated variables) are calculated based on some constraints and objective functions over some time horizon—i.e., moving horizon (for manipulated variables) and prediction horizon (for controlled variables). This optimization will be repeated using the receding horizon concept once the new information is available. In addition, the MPC has a filter gain that can respond quickly to inevitable signal to noise ratio changes while avoiding undesirable oscillatory control regimes.

The predictive control for the first time step is sent to simulated system as well as the system prediction model. The above steps are repeated using the updated simulated system states and disturbances for a desired simulation period. MPC is not a specific control strategy but a wide class of optimal control based algorithms that use an explicit process model to predict the behavior of a plant. There is a wide variety of MPC algorithms that have been developed over past 30 years [14].

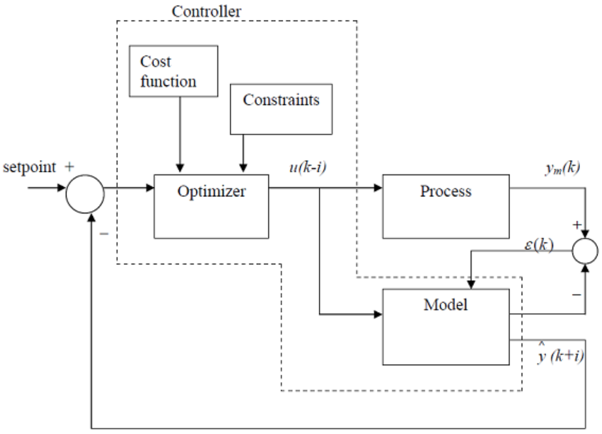

Figure 2: MPC of the basic logic structure

The basic elements of MPC are illustrated in Figure 2. and can be defined as follows:

1- An appropriate model is used to predict the output behavior of a plant over a future time interval or normally known as the prediction horizon (p). For a discrete time model this means it predicts the plant output from $y\hat{}_{(k+1)}$ to $y\hat{}_{(y\ k+H\ p)}$ based on all actual past control inputs $u_{(k)}$, $u_{(k-1),\ldots,}$ $u_{(k-j)}$ and the available current information $y_{(k).}$

2- A sequence of control actions adjustments $(\Delta u_{(k/k-1)})\ldots$ $\Delta u_{(k+m/k-1)})$ to be implemented over a specified future time interval, which is known as the control horizon (m) is calculated by minimizing some specified objectives such as the deviation of predicted output from setpoint over the prediction horizon and the size of control action adjustments in driving the process output to target plus some operating constraints. However, only the first move of computed control action sequence is implemented while the other moves are discarded. The entire process step is repeated at the subsequent sampling time. This theory is known as the receding horizon theory [15].

3- A nominal MPC is impossible, or in other words that no model can constitute a perfect representation of the real plant. Thus, the prediction error, $\varepsilon_{(k)}$ between the plant measurement $y_m(k)$ and the model prediction $y\hat{}_{(k)}$ will always occur. The $\varepsilon(k)$ obtained is normally used to update the future prediction.

The Figure M. illustrated the error feedback of MPC. MPC methods is developed for optimiztion; is very important topic. If criterion square is depended on by inputs and outputs solutions, linear function is explained. If tere are no constratied valus, by using iteractive approach for solving the problems which is the methods long [16].

The proposed MPC algorithm is applied to control the water supply network system to provide stable operation, improve performance costs, and reduce the cost of operation and save electricity in the event of having many pumps operating simultaneously, by manipulating the speed of one of the pumps and letting the rest to operate at the minimal speed. For the closed-loop simulation, the control algorithm was set up with the linearized model described earlier in equation 14, and step response of the model is obtained.

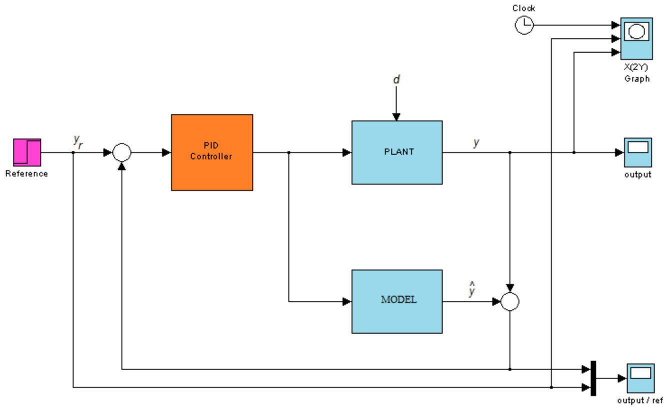

Figure 3: PID Control Model by Simulink

The new set points were introduced. The tuning parameters were chosen so that the integrated square error (ISE) between the simulated output and set point is minimized, as follows: $p = 15$, $m = 3$, $\Gamma^u = 0.95$ and $\Gamma^y = 1$. The pump operation was constrained between maximum value of 1000 rpm and a minimum value of 900 rpm.

Where, m is control horizon and p is prediction horizon and Γ^y is the diagonal output weight matrix and Γ^u is the diagonal input weight matrix. Feedback control loop for PID controllers designed in SIMULINK. PID control loop designed using SIMULINK is given in Figure 3.

Feedback control loop for MPC controllers designed in SIMULINK. MPC control loop designed using SIMULINK is given in Figure 4.

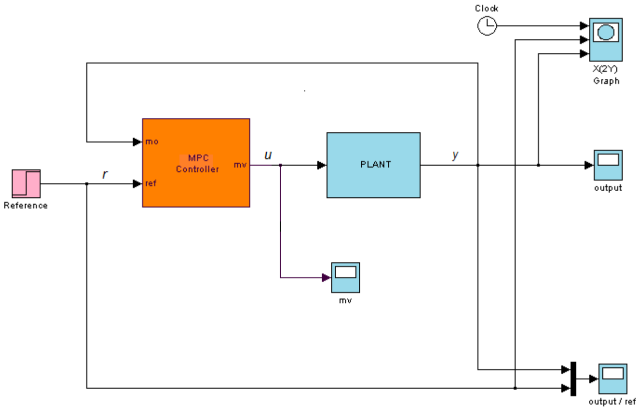

Figure 4 : MPC Control Model by Simulink

7. PID Control

PID controllers are used in the designed control system. PID controllers are designed usingthe convolution models of the system by utilizing continuous cycling or Ziegler-Nichols method with modified Z-N settings.Therefore, the controllers are further fine tuned by trial error procedure.

The fine tuned PID control parameters $K_P = 0.2948$, $K_I = 0.1275$ and $K_d = 0.3925$ are accepted.These PID settings are very small and cannot be implemented on a nominal operating industrial plant controller. However, if a computer is used for the PID controller, then these settings can be implemented.

Therefore in this study for comparison with the MPC, also placed on PID outputs flow rate to be able to compare PID controller with the MPC. In the design and testing of Model Predictive Control MPC as for PID controllers, two parallel working SISO MPCs are constructed using the model predictive control toolbox of MATLAB. Fig. 5 and 6 illustrate the closed-loop response of the output flow rate of the system to a desired steady state values, it can be noticed that all the controllers takes the system response to the new values, but their performance are comparable.

However, the rising time of the closed-loop response is faster in the case of unconstrained MPC comparing to the constrained MPC and PID controller, the constrained MPC has a good settling time slower than the settling time for unconstrained MPC and faster than the settling time for the PID controller, moreover, the constraint are kept within their interval which makes MPC a success control technique for controlling this water supply network system.

In general, it can be said that the MPC algorithm adapt quickly to changing conditions of the water supply network system, the MPC structure can be modified to meet possible requirements concerning energy consumption and to handle the constraints applied to the system.

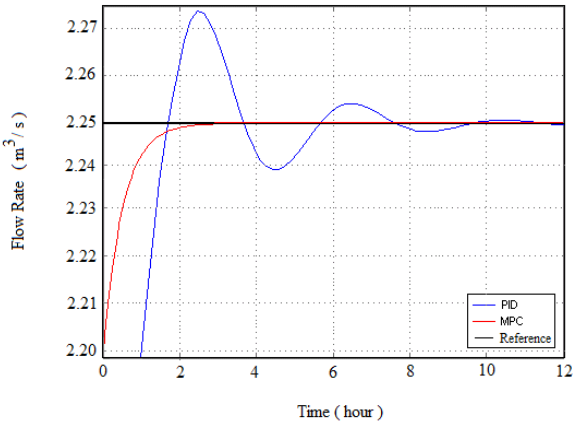

Figure 5: Comparison of MPC and PID results (ref = 2.25 m^3/s)

As can be seen at Figure 6 in references to the variable that is running under the process of MPC and PID control with the MPC there is a distinct difference between the answers of a more rapid response than the PID controller are given. MPC-line method, the reference value of thickness of less than 1% error with a permanent error with PID control method, permanently settled in around 1%. Describes the model predictive controller has a faster response than PID controller.

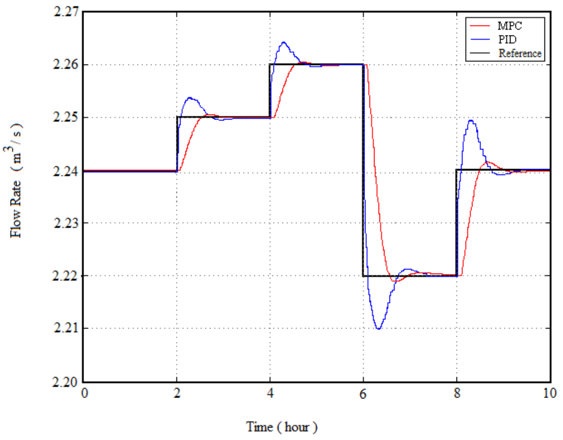

Figure 6 : Comparison of MPC and PID results (ref=2.22 m3/s -2.24 m3/s -2.25 m3/s -2.26 m3/s)

III. RESULT AND DISCUSSION

As a result of all this work 5% error rate remaining below the flow rate of the water supply systems, and literature are acceptable for the exchange of values is taken into account that the model predictive controller was developed to be reliable, the simulation results and performance of the best in the systems as well understood. As is clear from here the model predictive controller has a faster response than PID controller.Others studies in the literature, other MPC controller according to conventional controllers, and PID controller show that a new controller [16].

A proactive operation of the controller under different references, as defined in the system of restrictions and conditions for the simulations were defined. Constraints identified for water supply system. First, the control signals applied to the maximum and minimum values of the AC motor and supply pump (0-10 V, which corresponds) to 925-965 rpm and the constraints defined in system. The constrained and unconstrained responses of MPC controller show in Figure 7.

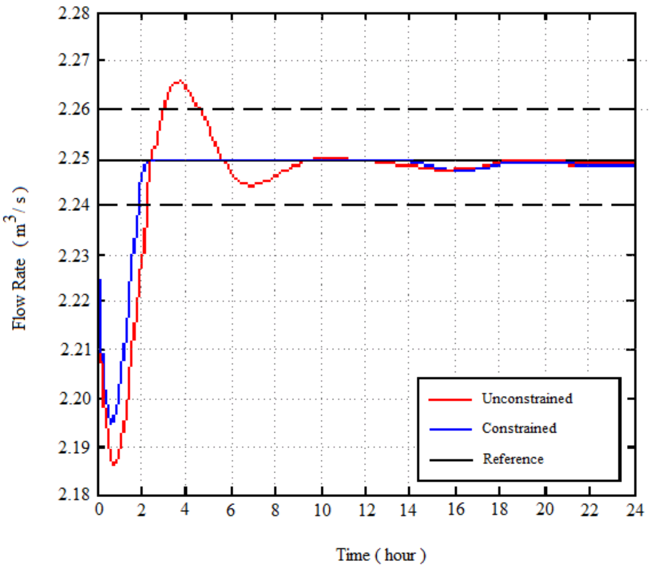

Figure 7 : Comparision of constrained and unconstrained MPC controller response

Figure 7. describes the unconstrained state has been % 6 pick after % 1.8 error and sit in 18. hours. Although the constrained state has been % 1 pick after % 1error and sit in 18. hours. The system has a structure that the constraints too. This control system, makes it difficult to be made with the classic multi-variable control algorithms. The results from this simulation and the

curve have been controlled successfully against the constraints of the MPC.

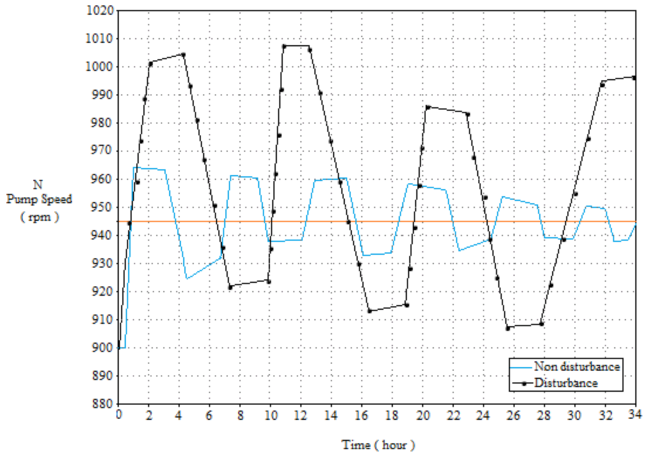

Figure 8. Changes of the Pump speed variables, ± 5% Output effect flow disturbance

The changes in the pump speed of the PST-1 shows by Figure 8. That occured a result of the square wave output load disturbance flow rate changes. The variable pump speed was reduced to 945 rpm at steady state when the PID and MPC controls were used.

IV. CONCLUSION

In this study, experimental and theoretical studies are done to design an inferential control scheme for the feedback control of flow rate in the water supply systems of Sirnak. The basic conclusions arrived are as follows:

For the two controllers designed, the analyses for robustness should be carried out also, in order to compare the controllers in this scope, which is also very important. Next to this, accomplishing comparisons of the results of the two controllers which are included in the linear model. Additionally, carrying out the real time applications by first discretizing the controller developed in this study, which are continuous, may be considered as a possible future work.

It is clear that the robust MPC technique with a moving optimization horizon, offer an effective means of dealing with the problem of water transfer operation to achieve goals such as flow rate regulation and cost minimization. This concept has the intrinsic ability to compensate for changes in water disturbance th at may occur at any point of the water supply system.

As a result, the model predictive control (MPC), the desired water supply system is controlled within acceptable limits. Compared with PID controllers, PID controller, MPC observed that the control system, such as variable references under the system successfully. However, given the restrictions on the model predictive controller based PID controller concluded that a more healthy work.

V. FUTURE WORK

The water supply system, in addition to the variable the water quality of supply systems can be controlled in a structure can be converted to variables. In this way, input increasing the number of output, the control problem becomes a bit more complicated. Example, the hygein material or clour material rates variables and density rates variables in supply water, pump power and pump type with the participation of the system against the performance of predictive control algorithm is the effect of dead time can be tested.

VI. ACKNOWLEDGEMENT

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