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SCADA Based Remote Monitoring and Control of Pressure & Flow in Fluid Transport System Using IMC-PID Controller

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Abstract: Ubiquitous sensing enabled for monitoring and control in the industrial sector are mostly WSN (Wireless Sensor Network) based systems or SCADA systems. WSN based systems are homogenous or compatible systems and they support coordinated communication and transparency among regions and processes. Hence in order to enhance the proprietary of remote monitoring and control technology, this paper emphasizes the development of architecture with local intelligent using IMC based PID controller can be integrated with DCS/SCADA and this research work spectacle only the development and application of Local Intelligence architecture for remote monitoring and control of concerned field parameters. This proposed local intelligence tactic governs the input and output from a hardware platform positioned on a process plant, organize added processing power for meticulous analysis in the control center by the use of software integration, data acquisition and logging on a created hybrid database, and spectacle significant processed post-data statistics to operators via a standard DCS/SCADA HMI. The established local intelligence is experimentally validated in the lab scale experimental fluid transport system to monitor and control pressure and flow rate parameters remotely by incorporating with CENTUM CS 3000.The simulation and experimental results of Local Intelligence using an IMC-PID controller on a lab scale fluid transport system are conveyed with its numerical data.

Keywords: Local intelligence, IMC based PID controller, Remote monitoring & control.

1. INTRODUCTION

Now-a-days, Supervisory Control and Data Acquisition (SCADA) systems [1, 8] are not climbable due to derisory memory and processing time, offers high cost of hardware drivers and management, not malleable when a process plant hardware needs to be updated, inflexible when there is a need for protocol change and software updating, and provides data and result with long delay. Hence, Human interfaced SCADA [4, 5] and the Engineering Internet are reconnoitered towards the improvement of modules used to identify the manifestation of impairment. In this upgradation era, all renovated industries has been assured using the emerging methodology remote monitoring and automation [19] which permit a pervasive bonding between the process plant hardware (sensors, actuators, control panel, etc.), smart hybrid objects and networked implanted devices to accumulate applicable data that will be

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communicated wireless manner to the remote information analytics center to be examined and modulated in order to construe the process and afford the appropriate decision in case of calamitous circumstances [7, 11].

This paper emphasizes a reliable monitoring and control with local intelligence using IMC-PID controller modular architecture design along with SCADA/DCS. This architecture with local intelligence using IMC-PID controller facilitates minimum human intervention will provide better workplace safety, maintenance of assets and will perform predictive maintenance of various industrial assets by analyzing various parameters (sensed data) and detecting failure modes either before they are going to take place or when the equipment will likely to fail or need service. This paper enlightens the brief information on the development of Local Intelligence using an IMC-PID controller which is present in the proposed IoT architecture.

To overcome the limitations of conventional remote monitoring and control systems [2, 3, 6], the proposed design of local intelligent offers a new utility monitoring and control system can amenably put up variations made to progress the functioning efficacy using an IMC-PID controller. The IMC PID tuning rubrics have the benefit of utilizing only a solitary tuning parameter to accomplish a vibrant trade-off between the closed-loop enactment and robustness. Over the unified incorporation of self-governing practicalities in a integrated checking and control system, an complete process system can be supervised and functioned in real time from the DCS/SCADA HMI through this local intelligence incorporated with IMC-PID controller which creates conceivable based automatic activation of tuning window block with trends, substantively enlightening engineering proficiency and working safety by exploiting CENTUM CS 3000.

2. LAB SCALE EXPERIMENTAL SETUP OF FLUID TRANSPORT SYSTEM

The lab scale experimental fluid transport system consists of the pumping unit, the transmitting pipes having a diameter of 1 inch about 15m long for the well-organized and extended transmission and manifold analog sensors at different distinctive locations with its corresponding control valves installed to compensate its drops/loss during the fluid transportation in the pipelines. The block diagram with local intelligence for the lab scale investigational setup envisaging the physical categorizations of apparatus positioned and also exhibits all the piping with directional tracks and equipment's facts with their controls is shown in Figure 1.

The process plant consists of two sections consisting of an electric pump, differential pressure transmitter holding a range of 03-15psi (0.1-3kg/cm^2), and pressure control valve at one section along with orifice flow meter having the limit of 0-1800lph, pump and flow control valve at another section. When the process plant is on track to run, initially reservoir tank fills up to 20% of its capacity, and then the electric pump is actuated to suck the fluid from the tank in order to transmit the fluid to each section. When the fluid starts to pass through the pipelines its corresponding pressure and flow transmitter send its present pressure and flow rate data to the I/O hub module station. During transportation to regulate the pressure and flow rate of the transmitting fluid, the opening and closing of the control valves are operated by the I/P converter in order to maintain its preferred effective range limits until the destination of the long run, till it drains from the process tank as shown in Figure 2. The Local intelligence will take the role to regulate and control the process plant parameters before it reaches the state of over limit/threshold. Since this paper encompass on the development and application of local intelligence using IMC-PID controller, the designed local intelligence can remotely monitor and control the pressure and flow rate as a separate loop through DCS/SCADA HMI which can be operated as stand-alone station without depending to a central server with mutual backup configuration by regulating the operation of the corresponding control valves to reach its desired operating points of pressure and flow rate.

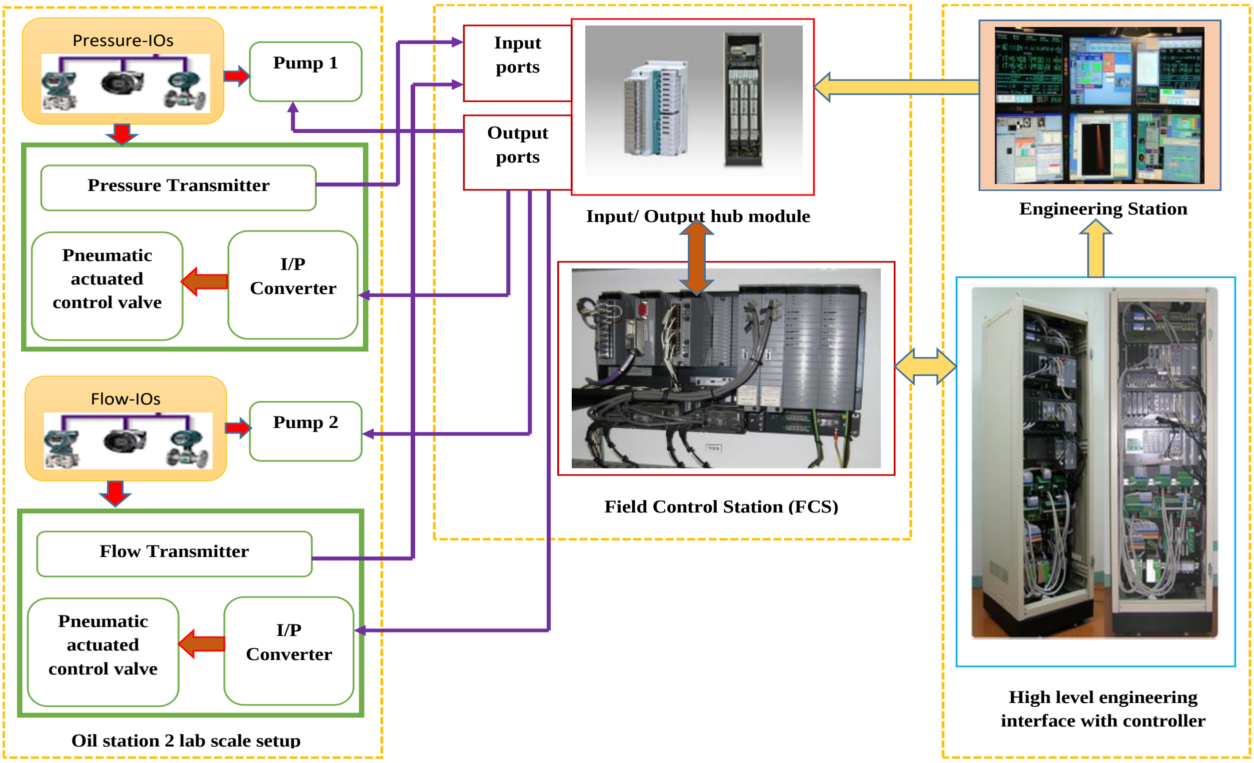

Fig. 1. Block diagram with local intelligence for the process plant.

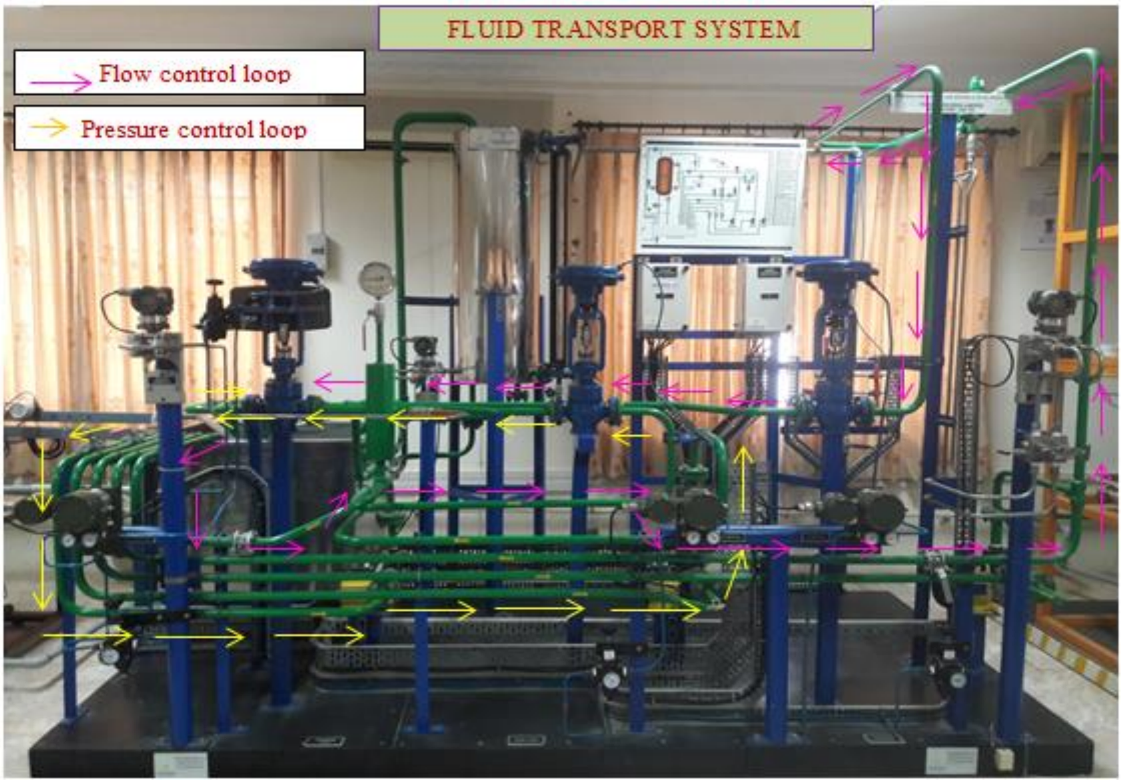

Fig. 2. The lab scale experimental setup of the fluid transport system

3.FUNCTIONAL DEPLOYMENT OF LOCAL INTELLIGENCE SCADA FRAME WORK

The SCADA incorporating local intelligence using an IMC-PID controller is developed for the experimental setup of the fluid transport system is shown in Figure 3 to deal with remote surveillance and control of flow and pressure and it also encompasses of individual interface displays for flow rate and its respective pressure parameters of the fluid as shown in Figure 3 and 4. The developed SCADA provides more functional utility options like system message banner, graphic view with graphics and control attributes, trend view, browser bar and tuning window.

The System Message Indication Window articulates the alarm existence eminence visually. The alarm existence eminence is presented by colors and blinking of action buttons, and the message presentation. The System Message Indication Window is constantly shown at the header of the SCADA HMI, so will never be veiled overdue by other windows. The browser bar is utilized to call up process and manipulative windows to entact the scheduled tasks. It also spectacles a list of task oriented manipulating windows and process hierarchical configurations in a tree-like manner, enabling the whole process plant to be effortlessly functioned. The graphics attributes view tool parades plants conditions graphically and can be instinctively activated and monitored. The control attribute graphic window shows the function block eminences by elaborating instrument faceplates.

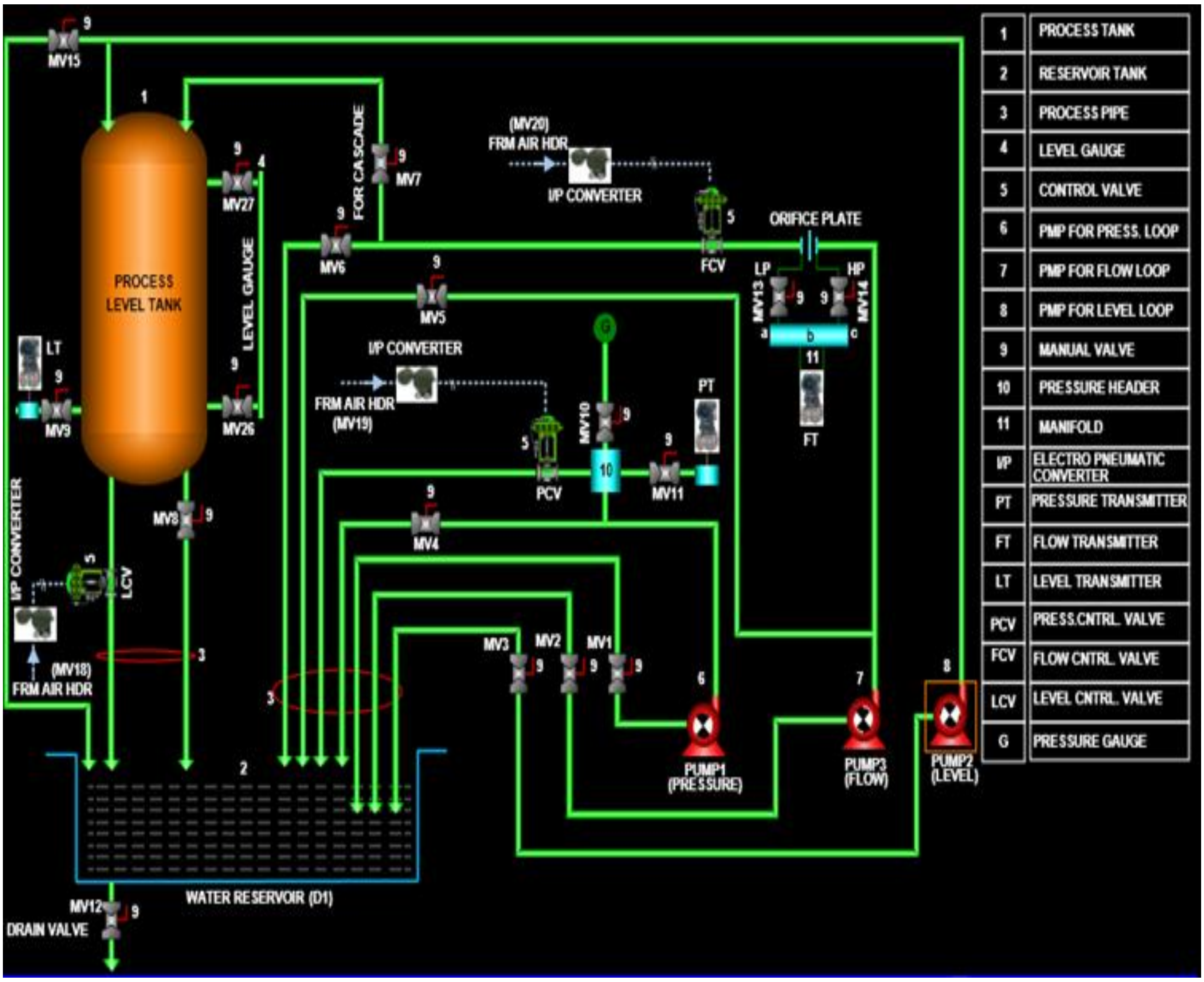

Fig. 3.SCADA view of the lab scale experimental fluid transport system

4. SYSTEM MODELING FOR PRESSURE AND FLOW CONTROL LOOP

4.1.Open loop response analysis

For modeling the fluid transport system, a transient response curve is chronicled by modifying the control valve opening in order to acquire the equivalent liquid pressure and flow rate changes on the pipeline in the open loop structure. This open loop experimentation reveals pressure of the liquid is at a maximum rate and the flow is at a minimum value when the opening of the control valve is around 10% of the overall opening and vice versa when the control valve opening reaches its full stretch of 100%.

Figure 4.Individual SCADA view of pressure and flow control loop

The open loop test run is carried out by linearly adjusting the percentage of control valve opening. The experimental analysis call ups with the initial flow rate of 179 lph and pressure of 2.2 kg/cm^2 and unremitting readings were documented until the flow rate and pressure influences a balanced/fixed state. The result divulges that for 100% control valve opening the ultimate flow rate and pressure accomplished are 1792 lph and 0.22 kg/cm^2. Open loop readings were noted for the percentage of control valve opening versus flow rate and pressure through Centum CS 3000 as displayed in Figure 5 and obtained data are presented in Table 1 by which the first order model considerations (process gain K_p and process time constant τ_P) are calculated. The evaluated model parameters for pressure and flow rate are given in Table 2.

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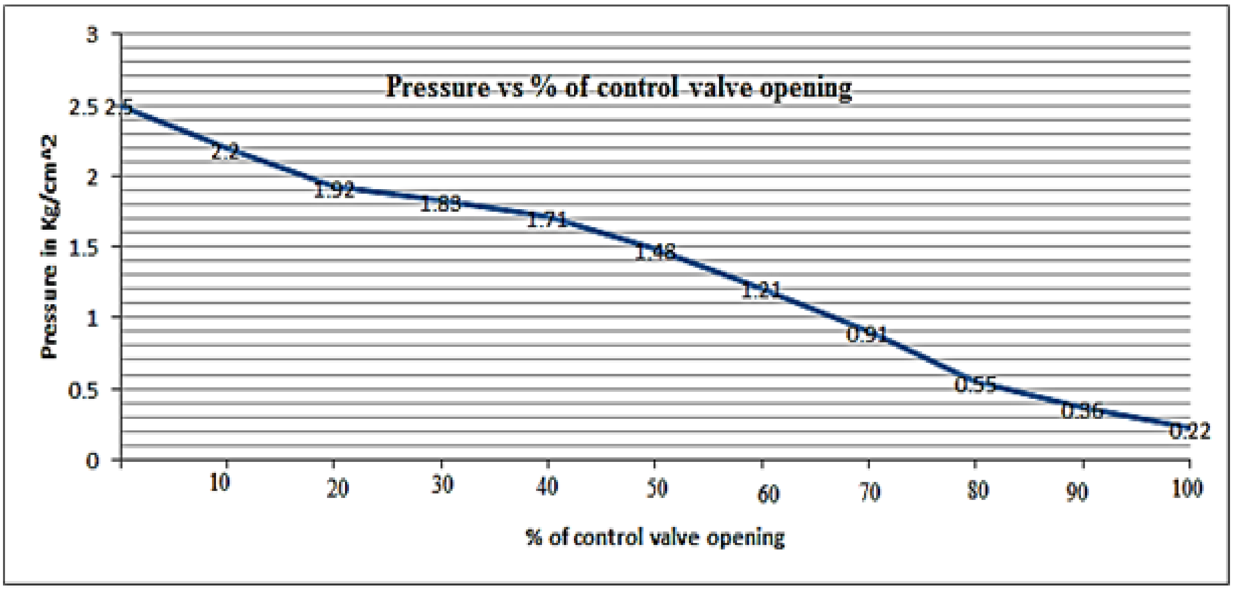
Table 1. Open loop response analyses of Pressure and flow for a different level of control valve openings

Percentage of control valve opening (in %)	**Flow rate (in lph)**	**Pressure (in Kg/Cm^2)**
10	179	2.20
20	230	1.92
30	373	1.83
40	468	1.71
50	585	1.48
60	757	1.21
70	919	0.91
80	1137	0.55
90	1429	0.36
100	1792	0.22

To enumerate first order strictures such as process gain Kp, process time constant Ʈp and time delay θ, with

$$Kp = \frac{[\text{Initial value} - \text{Final value of parameter}]/\ [\text{Maximum value of parameter}]}{[\text{Initial value of opening} - \text{Final value of opening}]/\ [\text{Maximum value of control valve opening}]}$$

$$\tau_P = 1.5 * [T_2 - T_1] \quad (4.1)$$



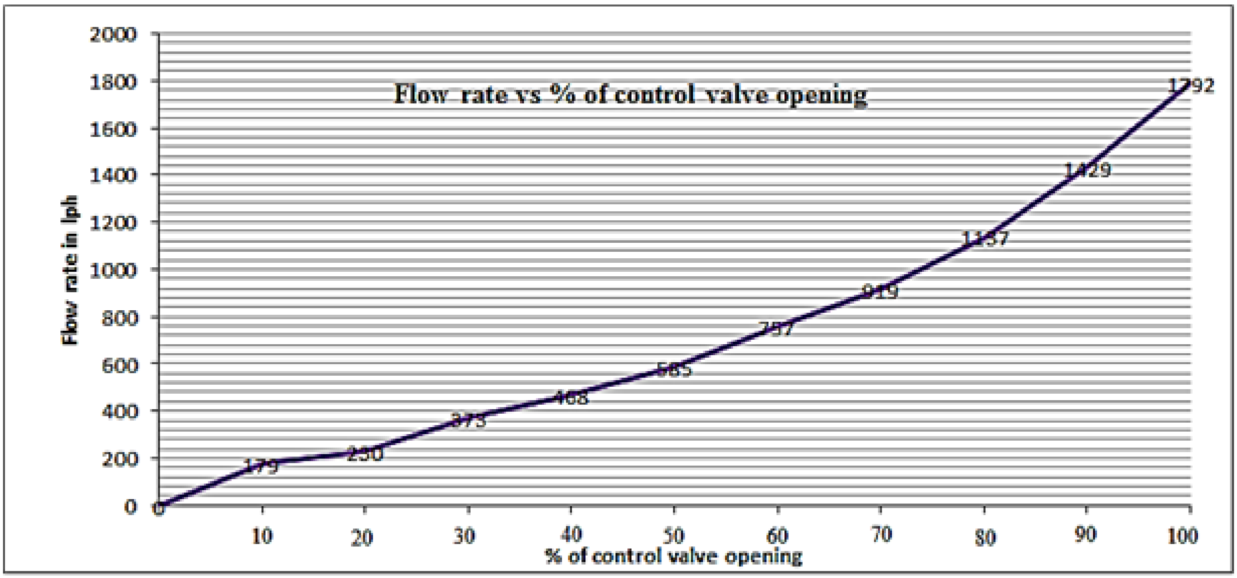


Fig. 5. Pressure and Flow rates of the liquid for the different level of control valve opening

T_1 at A1 = [Initial value of parameter- ((initial value of parameter– final value of parameter)*0.632)]

T_2 at A2 = [Initial value of parameter - ((initial value of parameter– final value of parameter)*0.283)]

$$\theta = (T_2 - \tau_P) \quad (4.2)$$

Table 2.Recognized model parameters at different % of control valve opening

Percentage of control valve opening (%)	Flow rate			Pressure		
	Kp	**Ʈp (sec)**	**θ** (sec)	**Kp**	**Ʈp (sec)**	**θ** (sec)
20	0.329	11.941	7.91	**1.681**	4.95	**13.58**
40	0.485	**8.317**	12.83	1.364	6.43	22.84
60	**0.914**	9.084	15.72	1.649	**4.026**	35.59
80	0.046	13.51	9.89	1.024	9.88	21.91
100	0.871	17.46	**5.16**	0.995	14.32	29.92

4.2.Model identification for pressure and flow control loop

From table 2, it shows that the behavior of a process is nonlinear and stable. Hence, First Order Plus Time Delay (FOPTD) transfer function ($G(s) = \frac{Kp}{\tau pS+1} e^{-\theta s}$) model is used to exemplify the pressure and flow rate maintenance of fluid transport system, where K_p = process gain, τ_P = time constant and θ = process delay. Then, the worst case model with the leading process gain and lowest time constant is designated to epitomize the process plant model [12, 13]. The identified FOPTD model for the flow control loop in the process plant is represented as,

$$G(s) = \frac{0.914}{8.317s+1} e^{-5.16s} \tag{4.3}$$

Similarly the FOPTD model for the pressure control loop is exemplified as,

$$G(s) = \frac{1.681}{4.026s+1} e^{-13.58s} \tag{4.4}$$

The system model identification is arrived by formulated the real-time experimental data obtained from the fluid transport system in open loop performance analysis on process plant [16].

5. ROBUST CONTROLLER DESIGN

The PID (proportional-integral-derivative) controller serves as one of the popular and extensively applied controllers in the industrial sector due to its uncomplicatedness, robustness and affords wide applicability to near-optimal enactment. Even though innovative control techniques can deliver substantial improvements, an elegant-characterized PID controller has ascertained to be suitable for an enormous quantity of engineering control loops. A PID type controller is used to optimize the performance of the control valve in edict to regulate and uphold pressure and flow-rate of the fluids being transported in the oil pipeline system. The proportional term ensures the trade of fast-acting modification which makes necessary alteration of output as rapidly as the error ascends. The integral part proceeds after a finite time but has the proficiency to create the steady state error as zero and the derivative term can advance proficiently the control loop performance.

5.1 Ziegler-Nicholas PID (ZN-PID) controller

The Ziegler-Nichols PID (ZN-PID) Controller is the utmost universally employed heuristic technique of fine-tuning a PID controller in all the engineering oriented feedback control application. The ability to predict the future errors in the process is possible in the PID controller, meanwhile, it can eliminate oscillations and can decrease the rise time in the performance [9]. Since the pressure and flow control process is the First Order based system with time delay characteristics, hence the implementation of ZN-PID controller is the benchmark of conventional techniques used for the comparative purpose. The parameters of ZN-PID controller is exposed in Table 3.

Table 3.ZN-PID controller tuning parameters with values

Tuning Rules	Tuning Parameters for pressure					Tuning Parameters for flow rate				
	K_c	τ_i (sec)	τ_d (sec)	K_I= (k_c/τ_i)	K_D= ($k_c*\tau_d$)	k_c	τ_i (sec)	τ_d (sec)	k_I= (k_c/τ_i)	k_D= ($k_c*\tau_d$)
$Kc = \frac{a\tau p}{\theta Kp}$ a∈ [1.2,2] $\tau_i = 2\theta$ and $\tau_d = 0.5\theta$	1.84	3.77	1.42	0.490	2.629	1.28	5.14	0.699	0.25	0.9

Where Kc is controller gain, τ_i, τ_d indicate integral time and derivative time.

5.2 Cohen-Coon PID (CC-PID) controller

Cohen-coon tuning system is the more difficult and complex form of open loop Ziegler Nicholas method and its tuning parameter relations were established empirically to afford closed loop reaction for a feedback system which sustains ¼ decay ratio. The reformed Cohen-Coon tuning procedures [9] is an outstanding scheme for attaining fast response on practically all control loops with self-adapting practices and to use on a non-interactive controller algorithm to provide a fast response on the process plant. The tuning parameters relations are given and their corresponding controller parameter of CC-PID is presented in Table 4.

$$Kc = \frac{1}{K_p} \cdot \frac{\tau_p}{\theta} \left(\frac{4}{3} + \frac{\theta}{4\tau_p} \right) \quad (5.1)$$

$$\tau_i = d \frac{32+6\theta/\tau_p}{13+8\theta/\tau_p} \quad (5.2)$$

$$\tau_d = d \frac{4}{11+2\theta/\tau_p} \quad (5.3)$$

Where Kc is controller gain, τ_i and τ_d are integral time and derivative time respectively.

Table 4.CC-PID controller parameters

Controller	Tuning Parameters for pressure					Tuning Parameters for flow rate				
	K_c	τ_i (sec)	τ_d (sec)	K_I= (k_c/τ_i)	K_D= ($k_c*\tau_d$)	k_c	τ_i (sec)	τ_d (sec)	k_I= (k_c/τ_i)	k_D= ($k_c*\tau_d$)
Cohen-Coon (CC-PID) controller	1.84	3.77	1.42	0.490	2.629	1.28	5.14	0.699	0.25	0.9

5.3. Internal Mode **PID (IMC-PID) controller**

The efficiency of the internal model control (IMC) strategy norm [9,11] has prepared it eye-catching in the process industrial sectors, where numerous endeavors have been done to accomplish the IMC standard to develop PI/PID controllers in cooperation with stable and unstable process system. The eminent internal model control-PID (IMC-PID) tuning rules have the improvement of solitary using of single tuning constraint to succeed a clear transaction between closed-loop presentation and robustness to exemplary inexactitudes and also serve as a newfangled online controller fine-tuning technique in closed-loop approach.

The direct synthesis upon disturbance (DS-d) technique proposed by Edghar and Seborg [14] can be considered into the identical class of the IMC-PID procedures, in that they achieve the PI/PID controller strictures by calculating the epitome feedback controller which contributes a predefined anticipated closed-loop retort. Even though the ultimate feedback controller upholding both the IMC and DS is habitually more problematical than the PID controller for time delayed practices, the controller arrangement can be condensed to that of either a PI or a PID based controller cascaded along with lower order filter by execution of applicable guesstimates of the dead time in process plant model. It is important to accentuate that the PI/PID controller premeditated according to the IMC procedure affords first-rate set-point tracking and consents the supervision of stable, unstable, and integrating system processes. This closed-loop fine-tuning method overwhelms the inadequacy of the renowned Ziegler Nichols unremitting cycling routine and contributes a reliably enhanced performance and forcefulness for a wide-ranging scheme of control process.

5.3.1 IMC-PI/PID controller design for fluid transport process plant

Figure 6(a) and (b) show the block diagrams of the IMC control [15-17] and corresponding traditional feedback control configurations, respectively, where G_p points the process, $\widetilde{G_p}$ denotes the process model, q and $f_r$indicates the IMC controller, the set-point filter, and G_c corresponds to the comparable feedback controller. For the trifling case (i.e.,$G_p = \widetilde{G_p}$), the set-point and disturbance reactions in the IMC scheme can be streamlined as:

$$Y = G_p q f_r + (1 - G_p q) G_p d \tag{5.4}$$

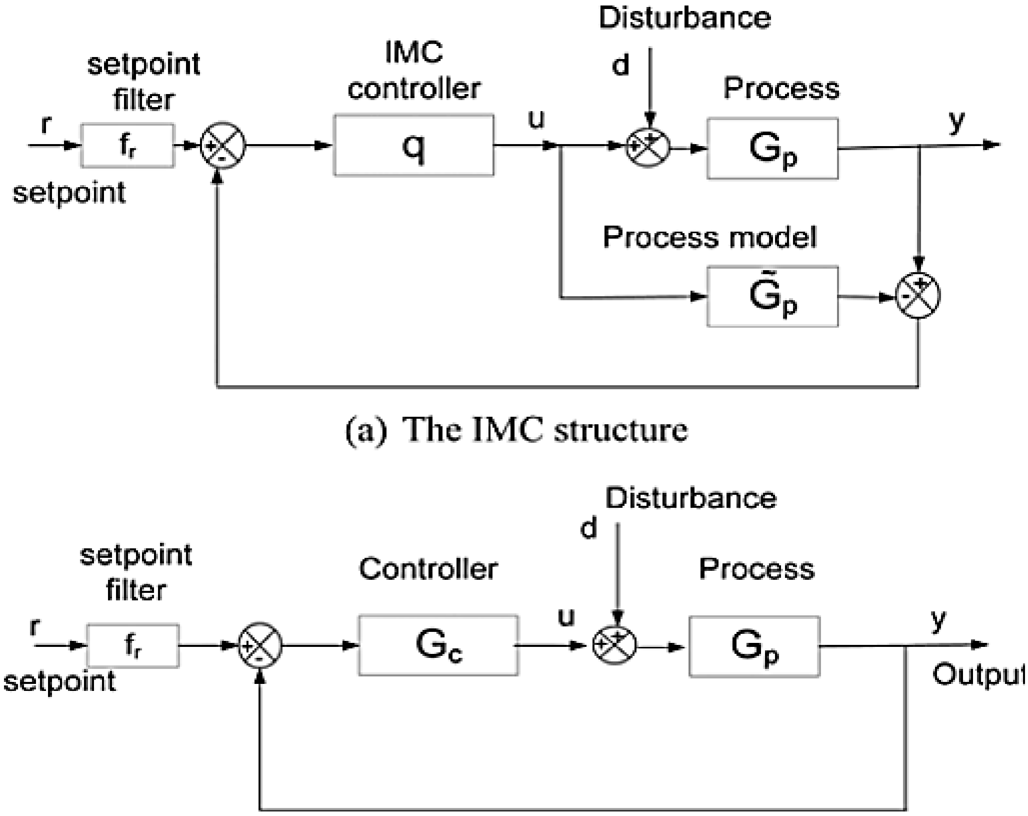
Conferring to the IMC characterization (Morari and Zafiriou [10]), the process model $\widetilde{G_p}$ is sub-mani folded as factor of two parts:

$$\widetilde{G_p} = P_m P_A \tag{5.5}$$

where p*m* is the percentage of the model reversed by the controller, p*A* is the ration of the model not overturned by the controller and p*A*(0)= 1. The non-reversible part typically embraces the dead time and right side occupied half plane zeros and is elected to be all-pass. To acquire a enhanced reaction for unstable or stable processes with poles situated near zero, the IMC controller q must gratify subsequent conditions: If the process G*p* possess unstable poles or poles positioned near zero at z1, z2… z*m*, then

(i) q must ensure zeros at z1, z2, …, z*m*

(ii) 1− G*p*q would also obligate zeros at z1, z2, …, z*m*



(a) The IMC structure

(b) Feedback control structure

Fig. 6.Block diagram of the IMC and corresponding conventional feedback control systems.

For a fluid transport system process the methodology is encouraged by the enactment enhancement of the disturbance rejection predominantly. The overhead design principles are obligatory for the internal steadiness of the unstable method. The supplementary profit of utilized criteria is that they support in the performance progress of the control loop systems. Meanwhile the IMC controller q is intended as $q = {P_m}^{-1}f$, the paramount condition is fulfilled inevitably. The second condition can be contented by conniving the IMC filter (f) as

$$f = \frac{\sum_{i=1}^{m} \alpha_i s^i}{(\tau_c s+1)^r} \tag{5.6}$$

where τc is an modifiable parameter of the fluid pipeline system which reins the adjustment between the enactment and robustness; r is nominated to be great ample to sort the IMC controller (semi-)accurate; αi are evaluated by Equation (12) to abandon the poles

$$1 - G_P q|_{s=z1,z2,\dots,zm} = \left|1 - \frac{P_A(\sum_{i=1}^{m} \alpha_i s^i)}{(\tau_c s+1)^r}\right|_{s=z1,z2,\dots,zm} = 0 \tag{5.7}$$

situated near zero around G_p. Then, the IMC controller emanates to be

$$q = \frac{{p_m}^{-1}(\sum_{i=1}^{m} \alpha_i s^i + 1)}{(\tau_c s+1)^r} \tag{5.8}$$

As a result, the resultant set-point and disturbance retorts are attained as:

$$\frac{y}{r} = (G_P q) f_r = \frac{P_A(\sum_{i=1}^{m} \alpha_i s^i + 1)}{(\tau_c s+1)^r} f_r \tag{5.9}$$

$$\frac{y}{d} = (1 - G_P q) G_P = (1 - \frac{P_A(\sum_{i=1}^{m} \alpha_i s^i)}{(\tau_c s+1)^r}) G_P \tag{5.10}$$

The numerator countenances $\sum_{i=1}^{m} a_i\, s^i + 1$ in Equation (5.9) reason to be occasionally an unwarranted overshoot in the servo response that can be eradicated by presenting the set-point filter f*r* to recompense for the overshoot in the servo response. As of the beyond design practice, a stable, closed-loop reaction can be reached by exhausting the IMC controller. The ultimate feedback controller that is correspondent to the IMC controller [18] can be articulated for the fluid transport system in expressions of the internal model $\widetilde{G_p}$ and the IMC controller q:

$$G_C = \frac{q}{1-G_p q} \tag{5.11}$$

Relieving Equations. (10) and (13) into (16) contributes the ideal feedback controller:

$$G_C = \frac{P_m{}^{-1}\frac{\sum_{i=1}^{m}\alpha_i s^i}{(\tau_C s+1)^r}}{1-\frac{P_A(\sum_{i=1}^{m}\alpha_i s^i)}{(\tau_C s+1)^r}} \tag{5.12}$$

The resultant controller in Equation (5.12) is substantially realizable for the fluid process plant, but it does not possess the customary PI/PID usage. The anticipated form of the controller can be attained by actuating the guesstimate of the dead time strategy in the process plant. Meanwhile, the final derivation exploits both easiness and estimate error due to dead time mode deliberated carefully during the PI/PID controller strategy. First order plus dead time (FOPDT) form is a descriptive model normally followed in the control process industries. On the source of the above detailed strategy principle, the FOPDT process plant has been reflected as

$$G(s) = \frac{Kp}{\tau pS+1} e^{-\theta s} \tag{5.13}$$

where K_p gives process gain, τ_P and θ denotes process stimulated time constant = process delay, the IMC filter nominated is

$$f = \frac{\alpha s+1}{(\tau_c s+1)^2} \tag{5.14}$$

After exploiting the above examined principle the ultimate feedback controller is specified as

$$G_c = \frac{(\tau s+1)(\alpha s+1)}{K[(\tau_c s+1)^2 - e^{-\theta s}(\alpha s+1)} \tag{5.15}$$

Subsequently the ultimate feedback controller in Equation (5.15) does not contain PI controller term; the residual assignment is to plan the PID controller that estimates the ideal feedback controller best meticulously. The ultimate feedback controller, G*c*, corresponding to the IMC controller [20], can be attained later by the calculation of the dead time allocated for the poles by Taylor series expansion, $e^{-\theta s}$ =1−θs and outcomes in

$$G_c = \frac{(\tau s+1)(\alpha s+1)}{K[(\tau_c s+1)^2-(1-\theta s)(\alpha s+1)} \tag{5.16}$$

Subsequently reorganizing of Equation (5.16) gives

$$G_c = \frac{(\alpha s+1)}{K(2\tau_c-\alpha+\theta)s}\frac{(\tau s+1)}{\left[\frac{(\tau_c{}^2+\tau_c\theta)}{(2\tau_c-\alpha+\theta)}s+1\right]} \tag{5.17}$$

From Equation (5.17), the consequential PID controller can be achieved after vulgarization as

$$Kc=\frac{\alpha}{Kp(2\tau i-\alpha+\theta)}\ ;\ \tau_i=\alpha\ \ ;\ \tau_d=\tau_2 \tag{5.18}$$

Where K*c* points controller gain, T*i* and τ_d are integral time and derivative time of the model designed process [21-24]. The significance of α (non-minimum phase element) is designated so that it terminates out the pole located at s=−1/τ and the rate of α is attained as

$$\alpha = \tau\{1-(1-\frac{\tau c}{\tau})^2 e^{-\frac{\theta}{\tau}}\ \ ;\ \tau_c=2\theta \tag{5.19}$$

By implementing this tuning procedure, it is conceivable to develop the enriched disturbance rejection action by adjusting the single fine-tuning of parameter in the controller. The important feature of this controller is that it compacts with the nonlinear and stable oriented plant system in a incorporated way. The parameters of the IMC-PID controller are revealed in Table 5.

Table 5.IMC-PID controller parameters

Controller	**Tuning Parameters for pressure**					**Tuning Parameters for flow rate**				
	K_c	τ_i (sec)	τ_d (sec)	$K_I = (k_c/\tau_i)$	$K_D = (k_c * \tau_d)$	k_c	τ_i (sec)	τ_d (sec)	$k_I = (k_c/\tau_i)$	$k_D = (k_c * \tau_d)$
IMC-PID controller	6.43	2.64	0.67	2.428	4.323	1.89	1.26	0.158	1.5	0.3

6. RESULTS AND DISCUSSION

The simulation and real-time investigational work have been conceded on the flow and pressure control loop outfit to examine the performance of the ZN tuned PID, CC-PID and IMC tuned PID controllers. To contrivance the closed loop control purpose, a PID block is established in the CENTUM CS 3000 in which feedback regulating signal is programmed to pass through the control valve to form closed loop feedback structure in fluid transport process plant.

6.1.Simulation Results

In the simulation work, the recitations of different controllers are equated by setting the peak of maximum uncertainty (M_s) value for comparison. It is noteworthy to ensure IAE, TV and M_s (Integral Absolute Error, Total Variation of the input, uncertainty margin value) to be lesser, but for a best characterized tuned controller causes the existence of trade-off, which indicates a declination in IAE infers an escalation in TV and M_s (and vice versa) [25, 26]. In the mean of the IMC and direct synthesis implied tuning mode τc is an changeable parameter and hence it can be altered it for the anticipated robustness (M*s*) level. In the simulation work of the current paper, recitals of various controllers are associated by setting the similar M*s* Value for a fair-minded comparison (i.e. M_s=1.26). The controller structure of the PID block for the fluid transportation system to monitor pressure and flow rate is developed using SIMULINK in MATLAB platform is presented in Figure 7 and 8.

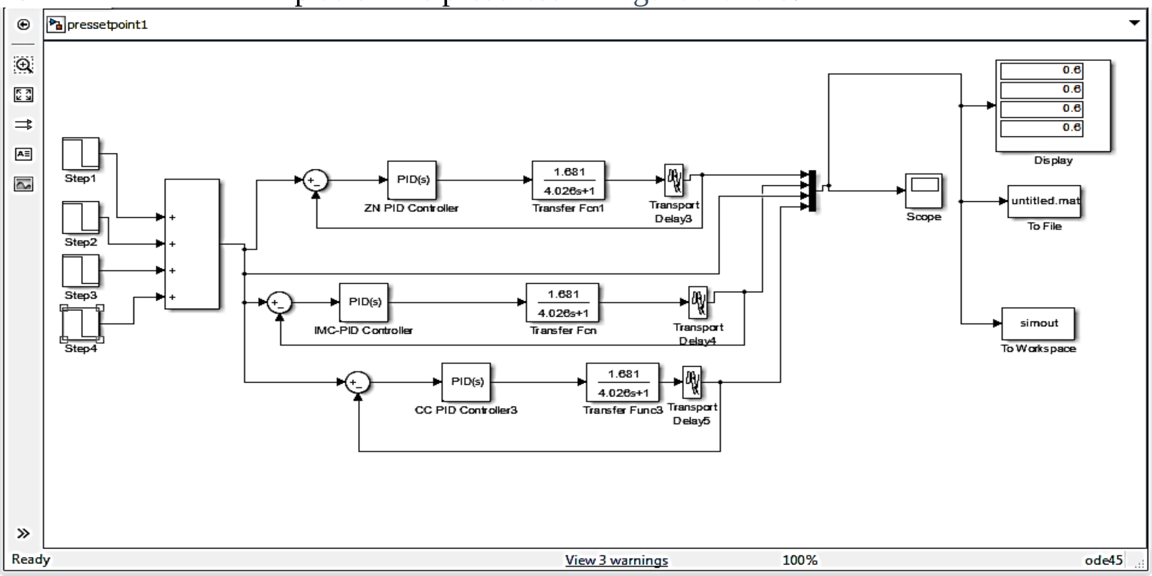


Fig. 7. MATLAB platform based created Simulink model for pressure control loop

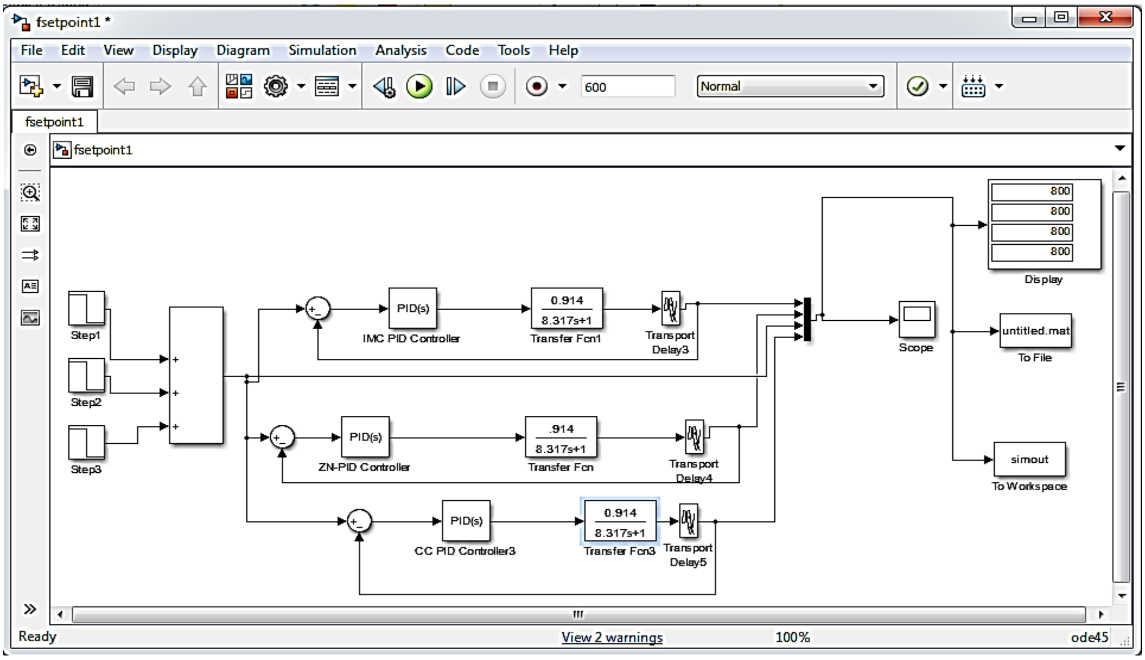


Fig. 8.MATLAB platform based created Simulink model for flow control loop

6.1.1. Performance analyses for pressure and flow control loop of process plant

The performance of ZN, CC and IMC-PID controller are investigated at required setpoint ranges in order to normalize both pressure and flow rate of the fluid being transmitted. The closed-loop simulated transient responses for pressure and flow rates at the operational choice of 500 lph and 3Kg/Cm^2 for the time interval of t = 0–50 s are unveiled on Figures 9a and 9b. From the Figures 9a and 9b, it is clear that the IMC-PID controller is enforced to trail the fixed operating point of pressure and flow rate at short duration of time of about 17 seconds and 15.5 seconds and maintain the steady state with overshoot as compared to ZN-PID and CC-PID control techniques which settle at about 34 seconds and 26.5 seconds for flow rate and 38.59 seconds and 47.987 seconds for pressure respectively. It confirms that IMC-PID controller offers 16.72% of improved quality indices on comparing with ZN tuned PID and CC-PID controllers. The presence of overshoot in the IMC-PID controller performance ensures high rise time with quickly settling on its desired set point in order to improve the experimented operating condition of the fluid transport system.

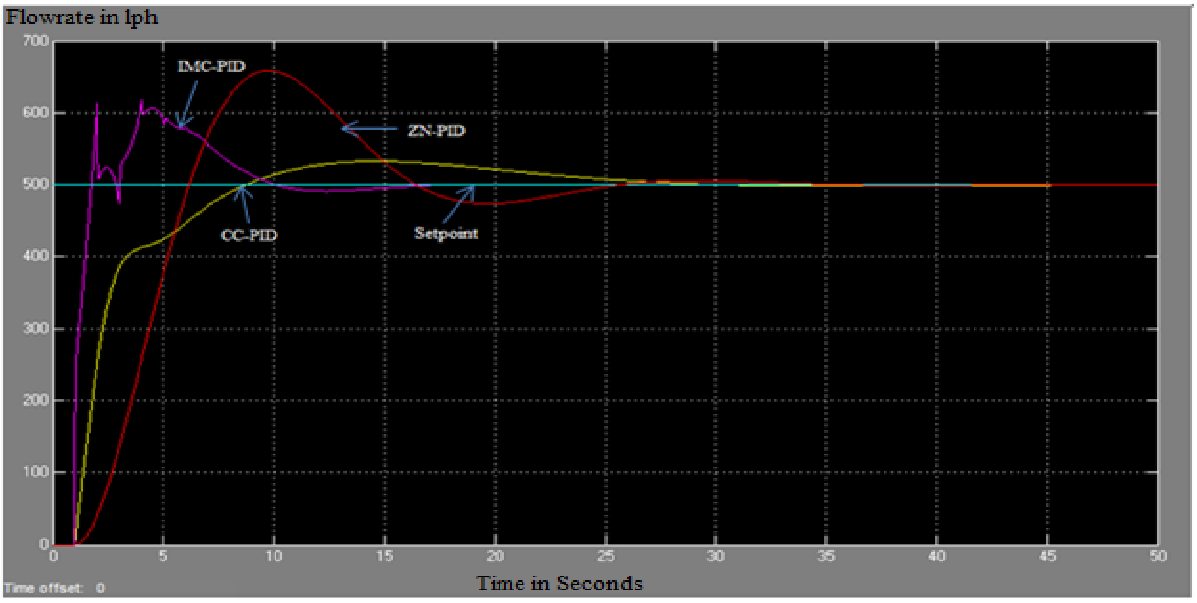


Fig. 9a . Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for flow control loop at a set point of 500 lph.

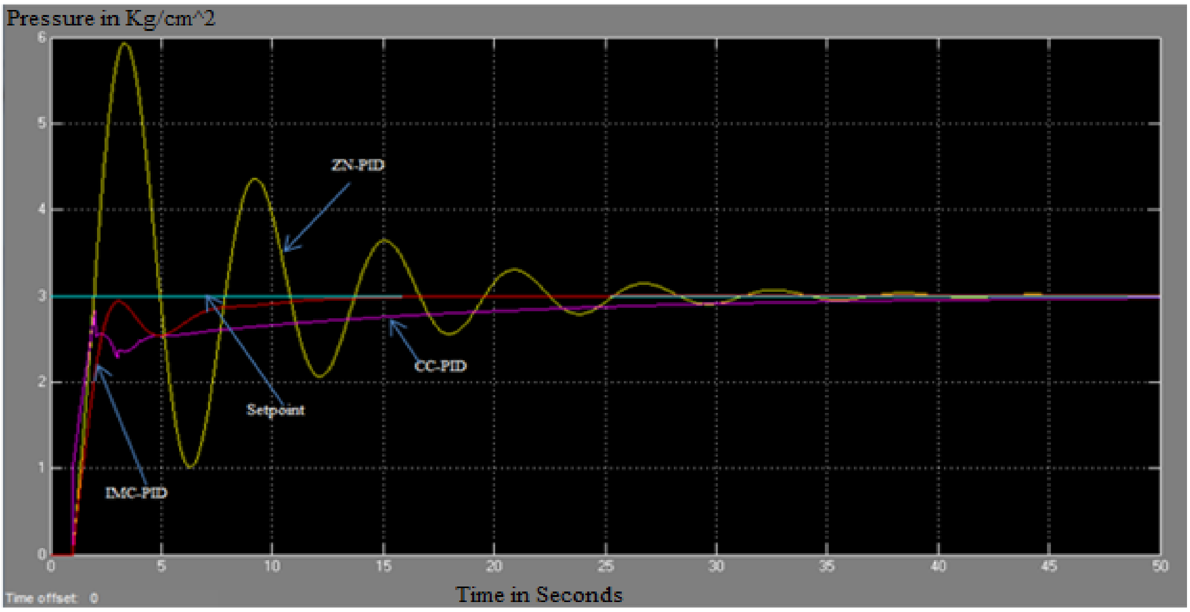


Fig 9b. Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for pressure control loop at a set point of 3Kg/Cm^2.

6.1.2.Setpoint tracking for pressure and flow control loop

Closed loop simulated transient responses attained at different operating points such as 0.7 and 1.6 Kg/Cm^2 for pressure and 900 and 1400 lph for the flow rate to confirm the robustness of the IMC-PID controller are shown in Figure 10 and 11. The Table 6 and Table 7 reveal that the performance of IMC-PID on comparing with ZN tuned PID and CC tuned PID controllers affords superior performance with the similar settings for altered operating points. Among the controller tuning rules, IMC-PID sustains the trepidations in the model parameters and pay for the extreme reliable and robust response when the operating point diverges. Figure 10 and 11 also ensures that IMC-PID controller endows least possible error indices of 20.94% as compared with ZN tuned PID and CC-PID controllers. This pragmatic IMC-PID controller confirms the boosted performance meanwhile it has the talent to trajectory on faults online.

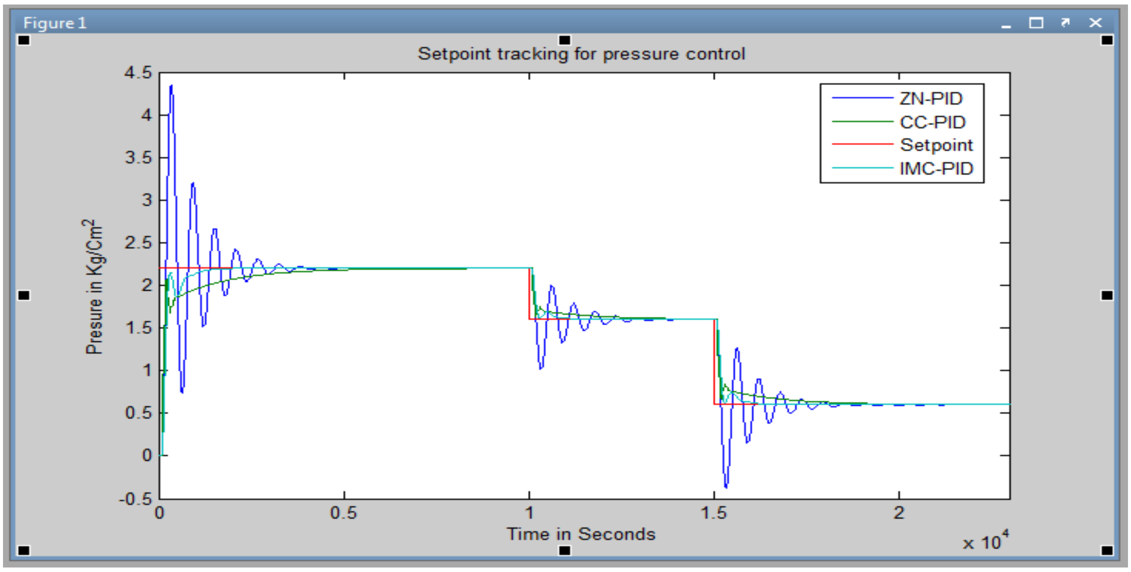


Fig. 10. Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for pressure control loop at different setpoint tracking.

Table 6.Pressure-Performance measures of the controllers at different operating points

Operating points in Kg/Cm^2	Error and Quality Indices Measures	**ZN-PID**	**CC-PID**	**IMC-PID**
0.7	ISE	0.00031	0.000435	0.001375
	IAE	0.0434	0.0405	0.037
	ITAE	0.1077	0.0749	0.04332
	t_r (Sec)	1.8	Nil	Nil
	t_s (Sec)	39.9	47.9	15.5
	$\%M_p$	36.214	Nil	Nil
1.6	ISE	0.00031	0.000441	0.001375
	IAE	0.04342	0.040529	0.037077
	ITAE	0.10772	0.040529	0.037077
	t_r (Sec)	1.76	Nil	Nil
	t_s (Sec)	39.102	46.32	16.2
	$\%M_p$	36.347	Nil	Nil
3	ISE	0.00034	0.000491	0.000253
	IAE	0.03590	0.024387	0.01444
	ITAE	0.01447	0.013514	0.012359
	t_r (Sec)	1.91	Nil	Nil
	t_s (Sec)	38.59	47.987	15.37
	$\%M_p$	37.102	Nil	Nil

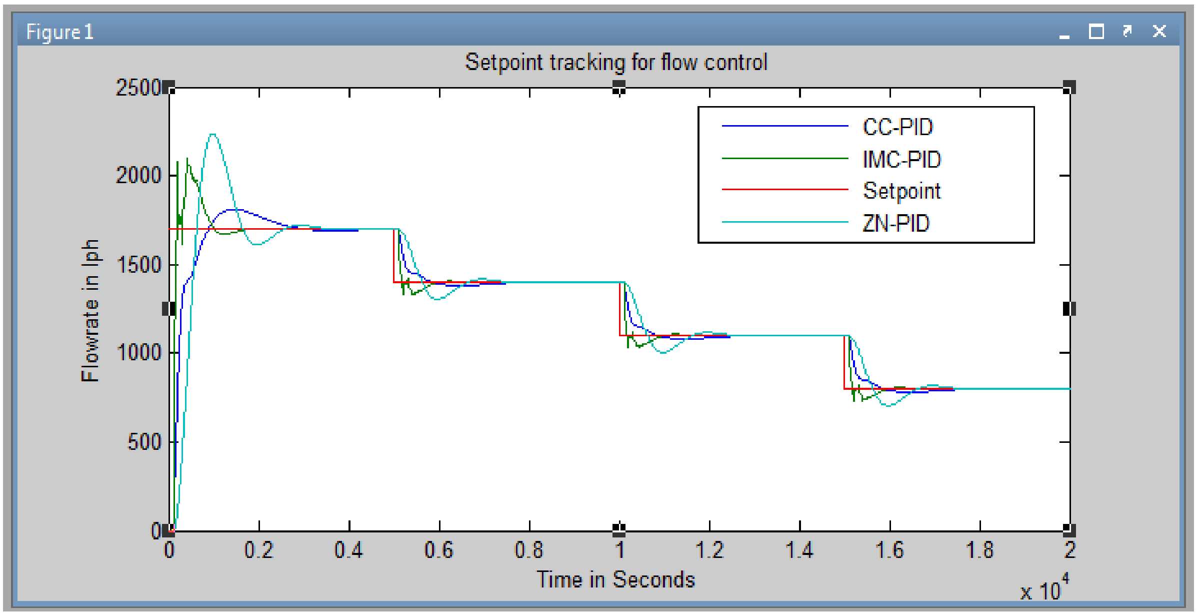


Figure 11. Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for flow control loop at different setpoint tracking.

Table 7. Flow rate-Performance measures of the controllers at different operating points

Operating points in lph	Error and Quality Indices Measures	**IMC-PID**	**CC-PID**	**ZN-PID**
500	ISE	0.000417	0.00044	0.000435
	IAE	0.02471	0.027021	0.028951
	ITAE	0.03691	0.039539	0.047324
	t_r (Sec)	2.1	6.3	8.99
	t_s (Sec)	17	26.5	34
	$\%M_p$	15.36	3.075	22.98
900	ISE	0.01667	0.0176	0.001741
	IAE	0.04943	0.054043	0.057901
	ITAE	0.02967	0.030249	0.030684
	t_r (Sec)	2.3	6.41	9.14
	t_s (Sec)	17	27.01	35.102
	$\%M_p$	14.89	3.152	21.39
1400	ISE	0.01887	0.000356	0.018872
	IAE	0.02409	0.02658	0.025112
	ITAE	0.03895	0.042130	0.043897
	t_r (Sec)	2	5.98	8.93
	t_s (Sec)	16.5	26.12	34.89
	$\%M_p$	14.57	2.936	21.134

6.1.3. Disturbance rejection test for pressure and flow control loop

The disturbance rejection performance is investigated at the operating point of pressure at 2.1Kg/Cm^2 and flow rate at 1300 lph. A step disturbance is introduced into the process by way of increasing the pressure to 3Kg/Cm^2 and flow rate to 1600 lph after the time period of 100 and 150 seconds as shown in Figure 12a and 12b. As of the analysis result endorses the merit by pointing only IMC-PID controller damp the disturbance in a smaller time period of 13 seconds with less undershoot of 11.33% as compared to the CC-PID and ZN-PID PID controllers on pressure control loop. The application of IMC-PID controller on flow control loop divulges the sluggish disturbance rejection of ZN tuned PID and CC-PID controllers where IMC-PID tolerates the disruption with a short span of 21 seconds with enhanced quality indices. The error and quality indices of the output signal are applied to estimate the disturbance rejection presentation of the controllers for pressure and flow rates are given in Table 8 and 9.

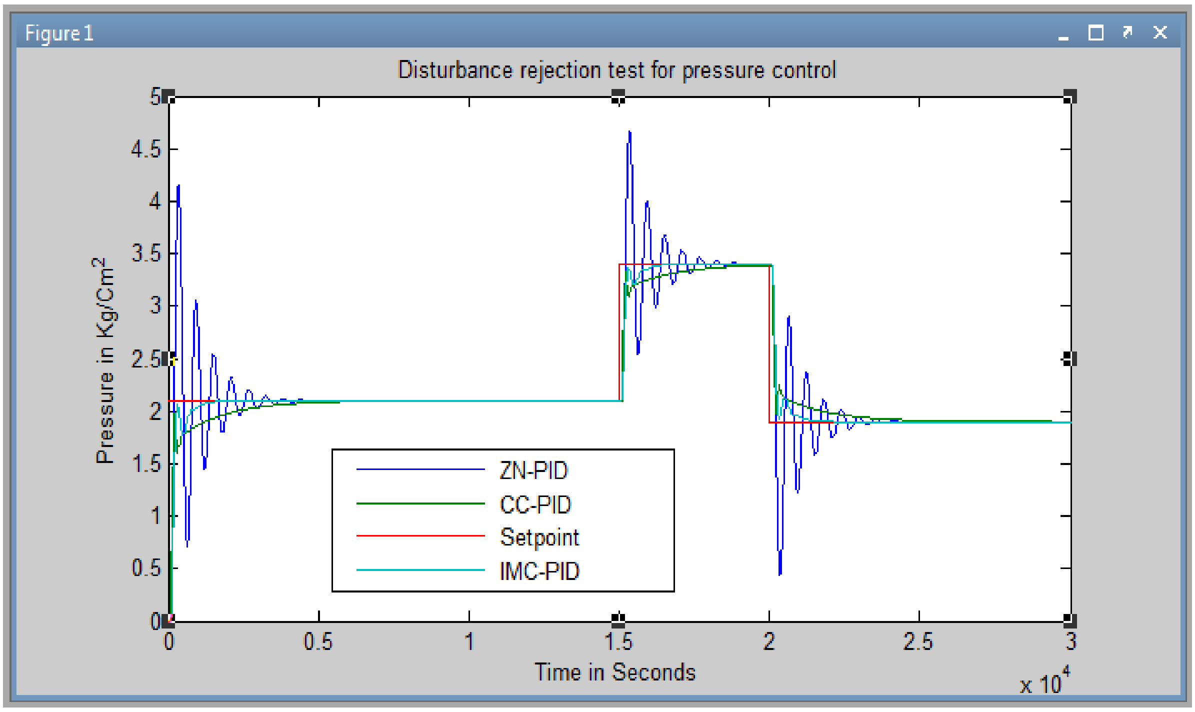


Fig. 12a. Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for pressure control loop after a disturbance at a set point of 2.1Kg/Cm^2.

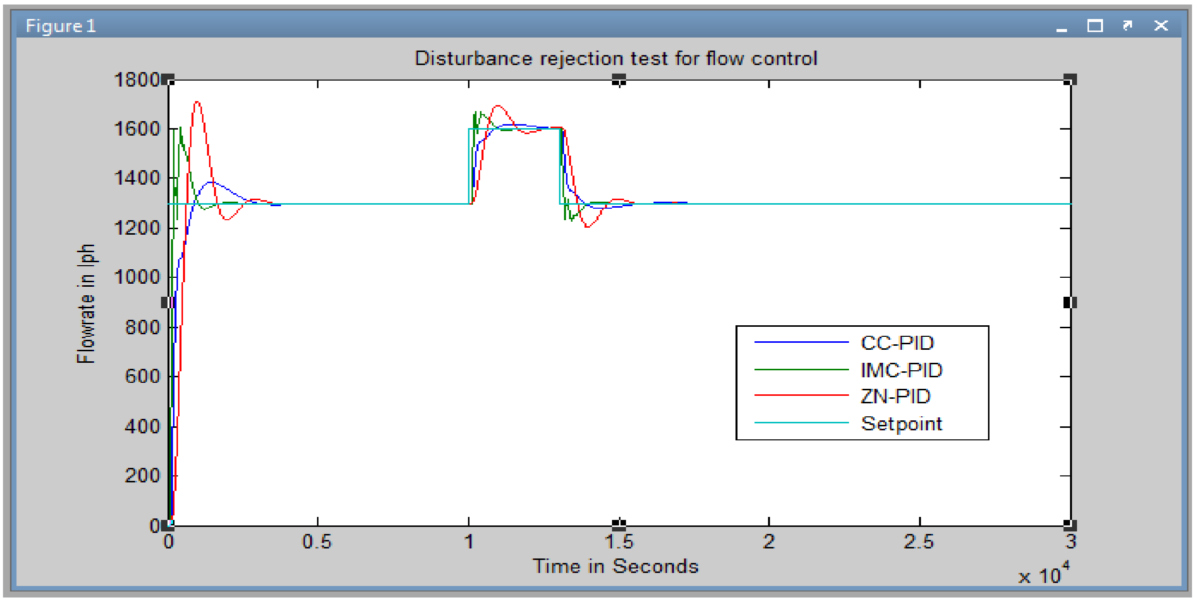


Fig. 12b.Performance analyses of ZN tuned PID, CC tuned PID, and IMC tuned PID controllers for flow control loop after a disturbance at a set point of 1300 lph.

Table 8. Performance measures after a disturbance at the operating point of 2.1 Kg/Cm^2

Performance Measures	**ZN-PID**	**CC-PID**	**IMC-PID**
ISE	0.000453	0.000418	0.000389
IAE	0.014475	0.013514	0.012359
ITAE	0.007482	0.008391	0.006453
t_r (Sec)	1.792	Nil	Nil
t_s (Sec)	39.02	48.13	16.19
%M_p	40.127	Nil	Nil

Table 9. Performance measures after a disturbance at the operating point of 1300 lph

Error and Quality Indices Measures	**IMC TUNED PID**	**CC TUNED PID**	**ZN TUNED PID**
ISE	0.039257	0.043302	0.042816
IAE	0.026801	0.028617	0.027843
ITAE	0.0141	0.018	0.0268
t_r (Sec)	5.34	8.921	13.973
t_s (Sec)	24.137	31.856	52.965
%M_p	19.357	3.954	33.045

Hence by simulation results, IMC-PID controller contributes optimal smallest settling time with least error integral value and highest robustness on comparing with ZN-PID and CC-PID controllers and hence affords 34.18% enhanced performance in monitoring and regulating the pressure and flow rate variations through the control valve opening and closing to attain the preferred operating choice at the destination in the fluid transport system process plant.

6.2.Real-time experimentation of local intelligence on fluid transport system

The proposed local intelligence using IMC-PID controller design performance is experimentally substantiated in real-time on lab-scale experimental set up of the fluid transport system. The control drawing for the process plant architecture is developed by creating two separate control loop blocks of PID controller for pressure and flow rate as shown in Figure 13. The resultant tuning values of PID controller using IMC technique which is confirmed through simulation is put on to the established local intelligence tune window using CENTUM CS 3000 R4 as shown in Figure 14. Through this control drawing builder option, hardware configuration gets synchronized with the flexibility of software customized application to the process plant in order to provide monitoring and control capabilities through online at a remote location from the process plant.

The process plant is starting to run by enabling the auto mode initiated by the local intelligence, when the fixed operating point for flow rate and its pressure is given in the corresponding monitoring particular field parameters faceplate present in the SCADA front end panel of the fluid transport system. After fixing the required operating range, the pump will be on track to run which is enabled by an operator remotely. The real-time successive data of both pressure and flow rate parameters of the fluid being transported is displayed continuously in Local intelligence trend view window in PIC100.PV/ FIC100.PV tag tab which is present below the trend graph and these data can be exported to excel by exhausting local utility data box option.

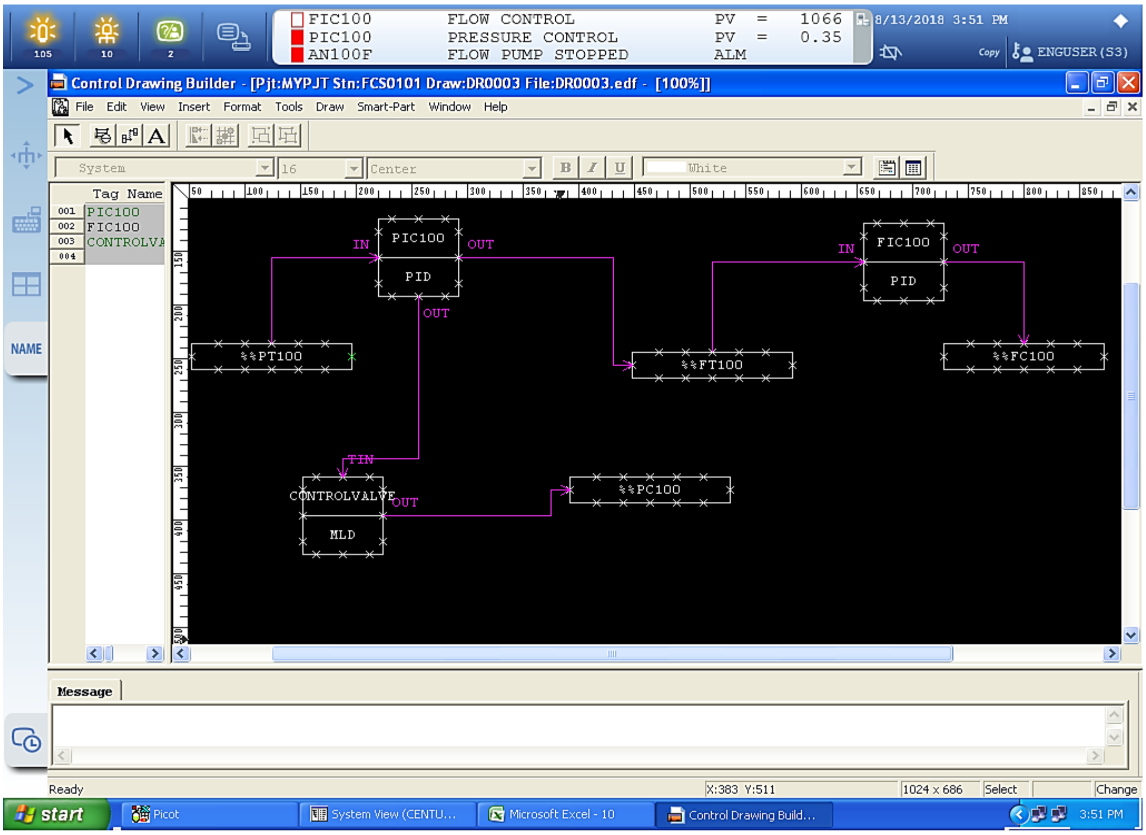


Fig. 13. Control drawing for fluid transport system process plant

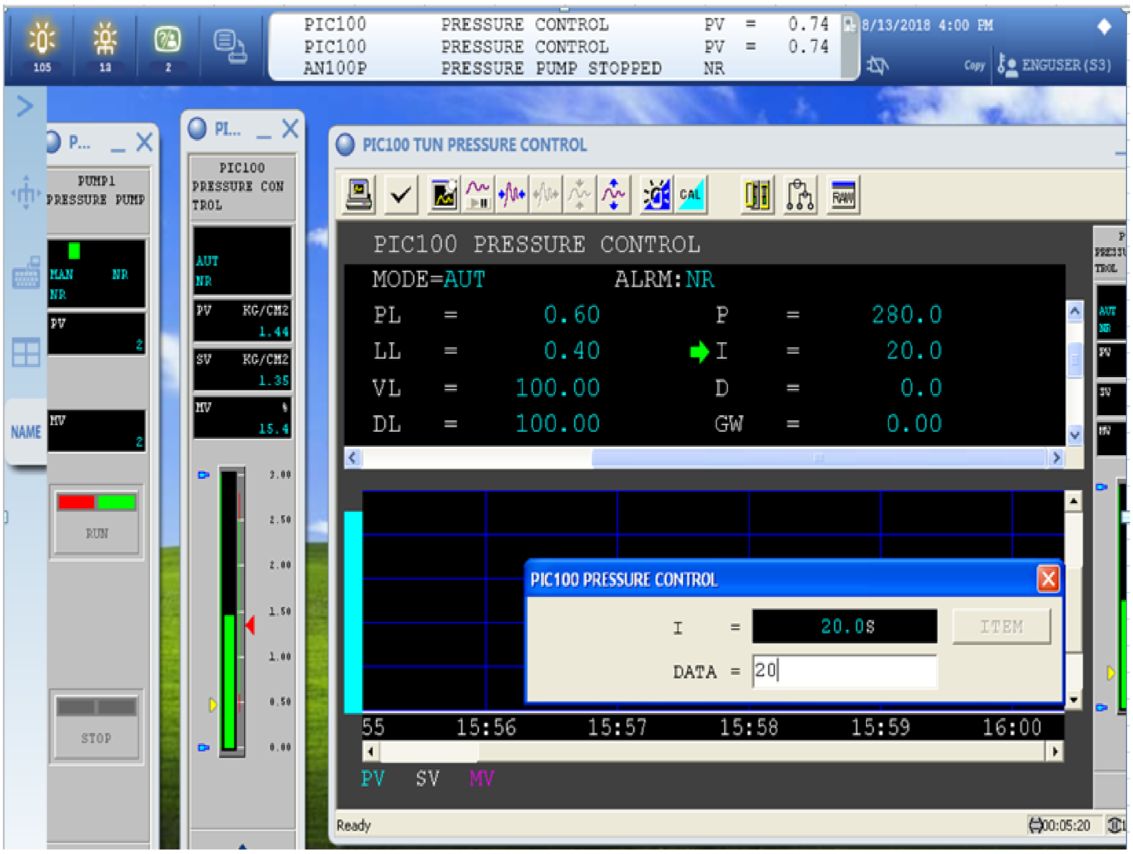


Fig. 14. Developed Local intelligence tune window of PID controller for the process plant.

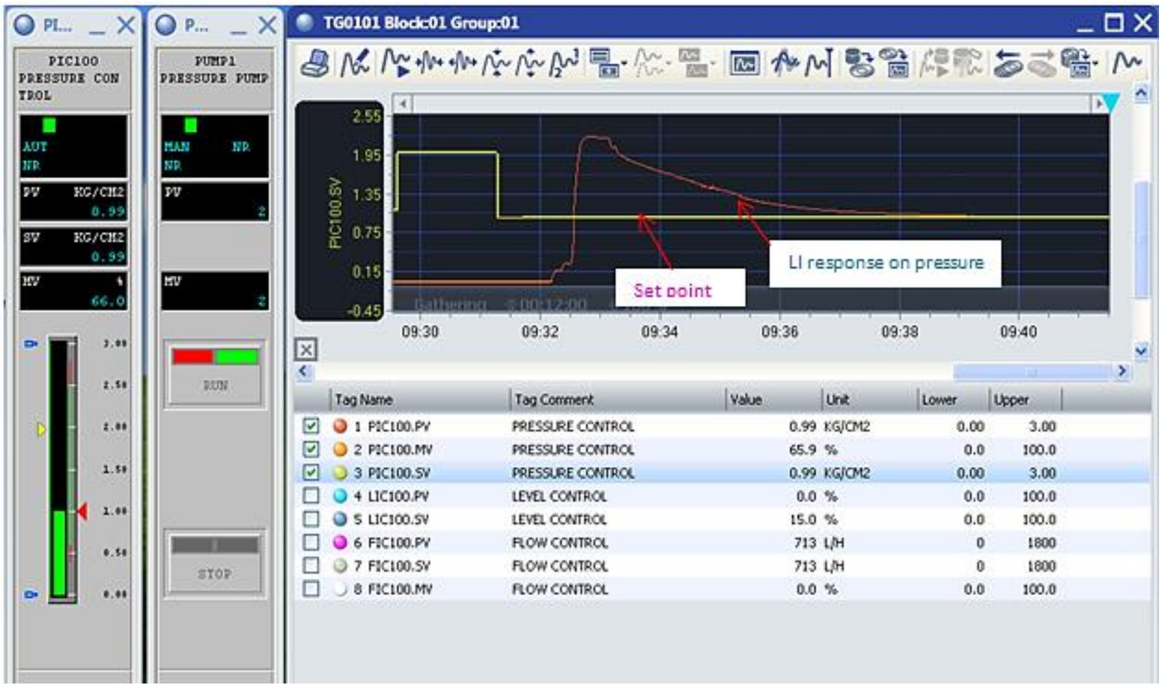


Fig. 15. Real-time monitoring and control of Pressure through Local Intelligence using an IMC-PID controller.

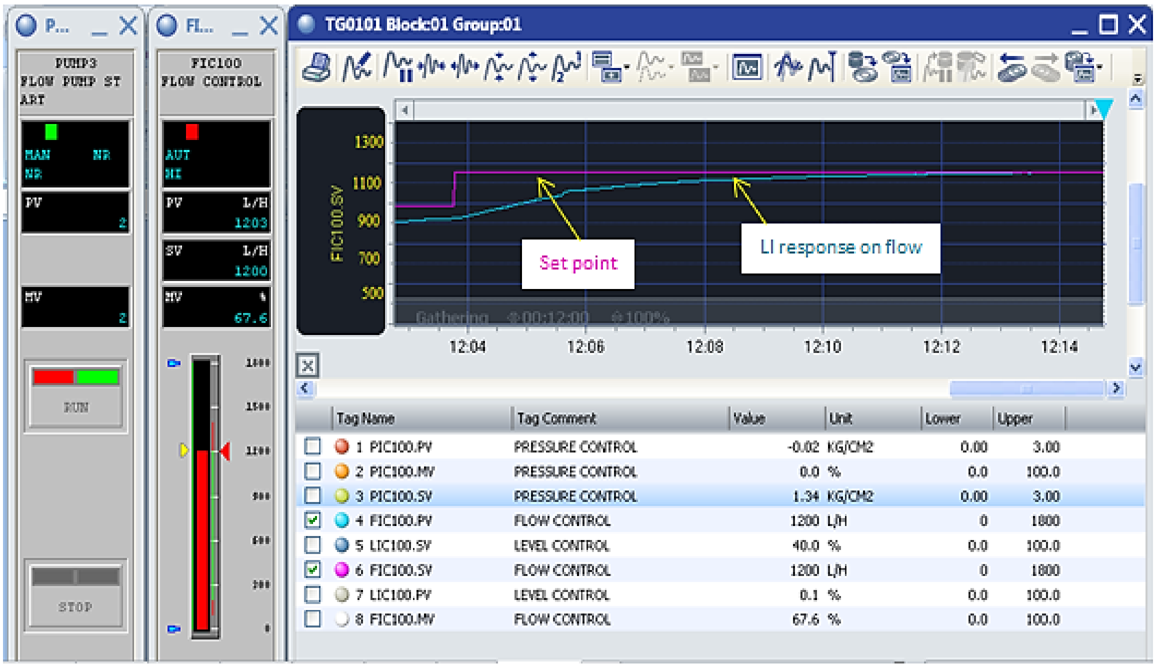


Fig. 16. Real-time monitoring and control of Flow rate through Local Intelligence using an IMC-PID controller.

Figure 15 and 16 reveals the performance of Local intelligence using an IMC-PID controller on remote surveillance and control of flow rate and its pressure on the implemented process plant. The setpoint of pressure and flow rate is given as 0.99Kg/Cm^2 and 1200 lph respectively. Based on the operating set point, the developed IMC-PID controller running on the back end of the Local intelligence SCADA adjusts the feedback signal going from the remote master control panel to the I/P converter incorporated with corresponding pressure control valve and flow control valve to regulate its opening and closing installed on the process plant control loops.

The real-time experimentation discloses that when the percentage of control valve opening gets increased, the field parameters as like pressure and flow rate of the fluids passing through the pipelines get decreases and increases consistently. The developed Local Intelligence using

IMC-PID controllers authorizes the enriched performance meanwhile it has the capability to trajectory of errors occurrences through online by making real-time process plant information easily accessible through the online applications by its connectivity and interoperability.

7. CONCLUSION AND FUTURE SCOPE

The development and investigation of Local intelligence using an IMC-PID controller on the real-time fluid transport process plant are carried out in this paper. The real-time experimental results show that this Local intelligence using IMC-PID controller acts with provisioning smart decision making on the real-time data of the field parameters in order to optimize the process plant with minimum losses by means of its affordability and the reliability to conduct measurements remotely and in real-time of monitoring and control of field parameters. The experimental validation emphasizes has been engineered to condensed downtime, upgraded system accessibility, enriched control consistency, and unremitting system access. I/O remote-hub module with control server, operator and engineer stations handling data organization, and gateway utilities are disseminated on an Ethernet linkage to confirm system veracity and well-timed data broadcast communication. The evaluation of this Local intelligence ensures that Condition Based Maintenance with the proactive event-driven computing paradigm for fully exploiting its capabilities by enabling proactive maintenance decisions ahead of time on the process plant, so that the operator can react pre-emptive prior to sort out occurrences of any failure on the process plant.

Regarding the future work, an internet of things (IoT) based reliable monitoring and control with local intelligence using IMC-PID controller modular architecture design along with SCADA/DCS which is outlined in this paper will be implied and investigated on this lab-scale fluid transport system process plant. It is evident that the proposed IoT architecture will offer a promising and a novel infrastructure to remote monitoring and control in any industrial sectors.

CONFLICT OF INTEREST

All the contributors in this research work have no clashes of attention to announce and broadcasting this article.

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