Control of a Continuously Variable Transmission System

Mohammed Ahmed, Ejike Chibuzo Anene, Hassan Sabo Miya, Saidu Kumo Mohammed

Abstract—This paper proposed control strategies for the modern mechatronic Continuously Variable Transmission (CVT) System using three different techniques; The Ziegler-Nichols, Linear Quadratic and Pole-Placement methods. The results of the system responses of the designed control schemes were successfully simulated using MATLAB. Comparing the results showed that controller implemented using the Pole-Placement method was the best for the system which gave a rise time of 335milliseconds, paek time of 400milliseconds, settling time of 290 milliseconds and an overshoot of 0.72 percent.

Index Terms—Controller, Continuously Variable Transmission (CVT) System, Ziegler-Nichols Method, Pole-Placement method, Linear Quadratic Regulator method.

I. INTRODUCTION

The Continuously Variable Transmission (CVT) System which had been in state of neglect for many years has now become an area of focus for research due to high concern in fuel consumption. The CVT which was initially developed for industrial machines, over the years it has received attention in the automobile application because researches have shown that it is a good economical alternative with improvements in design, materials and electronic control options. The improvements have made cars with such systems fuel efficient and very fast in response and hence overall performance [1]. As mentioned earlier the CVT system was used for machines used in manufacturing industries. In between 1934 and 1938 a variant 'Perbury gear' was used on Austin cars. Another variant called 'Varionic' which was developed by Van Doome in 1958 was used on DAF33 truck; it was improved in the 1970s and used for DAF66. In 1962 Honda manufactured the hydraulic based continuously variable transmission system for a scooter engine and in 1972 the 'V-matic' which a CVT system with dry-belt for cars. In 1984 it was used on the Fiat Uno, the Ford Fiesta, Subaru Justy and Nissan Micra cars. Honda in 1996 developed the 'Honda Multi Matic' which was applied for Honda Civic 1.5 and 1.6 litre engines.

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The 'M6 hyper-CVT' developed by Nissan was installed on its 2.0 litre Primera. The Audi developed the superb 'Multitronic CVT', after which was the Nissan CVT. Another remarkable achievement is the incorporation of the CVT system on the Canon Williams Renault Formular One race car in 1993. Therefore, the CVT is undergoing remarkable improvements portraying to be a promising alternative in the future [1].

II. METHODOLOGY

The plant adopted for the paper was the modern mechatronic Continuously Variable Transmission System used by [1] in his work which is a third order system given by equation (1).

$$G_{CVT}(s) = \frac{1}{s^3 + 6s^2 + 11s^2 + 6} \quad (1)$$

Control strategies were developed using; the PID control approach, utilizing the Ziegler-Nichols method and state space approach utilizing the Pole Placement and Linear Quadratic Regulator methods. Considering the simplest PID control scheme [2], the system can be represented as shown in figure (1) below.

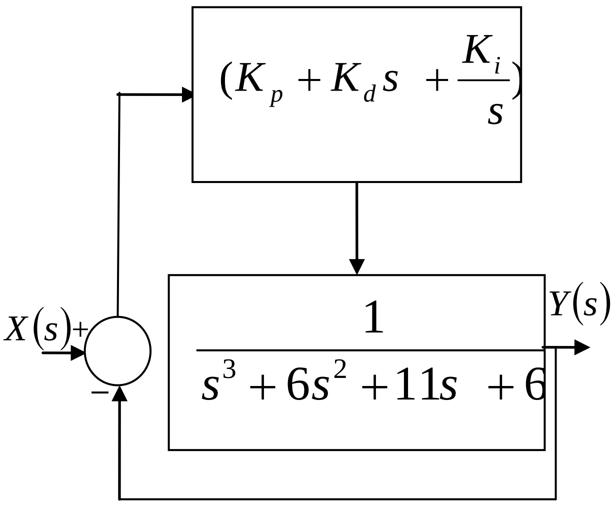

Figure 1: Block Diagram of the System with PID Controller

The transfer function of the system becomes;

$$\frac{Y(s)}{X(s)} = \frac{s^2 K_d + sK_p + K_i}{s^4 + 6s^3 + (11 + K_d)s^2 + (6 + K_p)s + K_i} \quad (2)$$

The Ziegler-Nichols method can then be used to determine the controller parameters K_p, K_i and K_d which are the proportional gain, integral gain and derivative gain constants respectively, such that the system will have a good performance. Figures 2 and

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3 are the simplest block diagrams of the CVT system using LQR and Pole-Placement control scheme respectively for these strategies the challenge is determination of the matrix **K**. using the LQR scheme K is determine by minimizing the cost function in equation (3), while for the Pole-Placement the poles are placed at a suitable points that improve the system performance as well as stability [3].

$$J = \int_0^\infty (x^* Qx + u^* Ru)dt \qquad (3)$$

Q is a positive-definite or positive-semi-definite Hermitian or real symmetric matrix and R is a positive-definite Hermitian or real symmetric matrix. The matrices Q and R account for the error and the energy expenditure of the system [3].

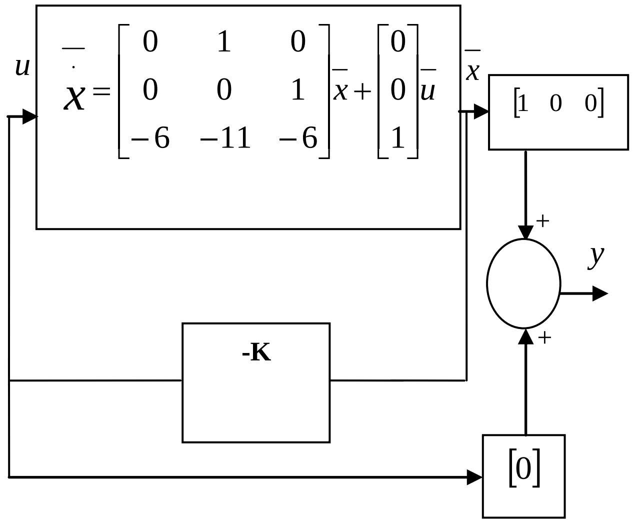

Figure 2: Block Diagram of the System LQR

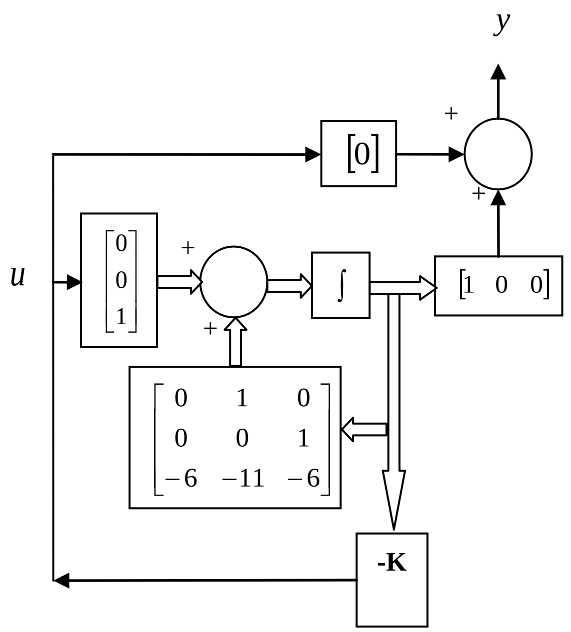

Figure 3: Block Diagram of the System using Pole-Placement

III. DISCUSSION OF RESULTS

The results were obtained by simulation using SIMULINK/MATLAB. The MATLAB software however is widely used and serves as an important tool for control systems analysis and designs [4-6]. The controller parameters; K_p, K_i and K_d using the Ziegler-Nichols method were obtained as; 16, 10, and 6.7 respectively. The **K** matrix elements; k(1), k(2) and k(3) using the LQR controller for the system were determined as, 4285.5, 1074.5 and 104.4 respectively. And the **K** matrix elements; k (1), k (2) and k (3) using the Pole-Placement technique controller for the system were determined as; 9999, 1300 and 61 respectively, with the poles of the system at, -10+j20, -10-j20 and -20. Figures 4, 5, 6 and 7 are the Unit Step Responses of the system without controller and with controller obtained using the Ziegler-Nichols method, without controller and with controller designed using the Linear Quadratic Regulator method, without controller and with controller designed using the Pole-Placement method and with all the control strategies respectively. Also, from the graphs response parameters were determined as shown in table 1 which showed that the Pole-Placement method produced the best result followed by the Linear Quadratic Regulator method, then the Ziegler-Nichols method.

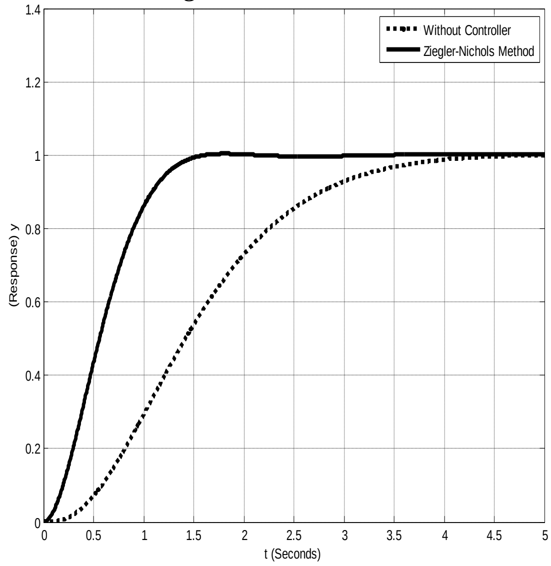

Figure 4: Unit Step Response without and with Ziegler-Nichols Method Controller

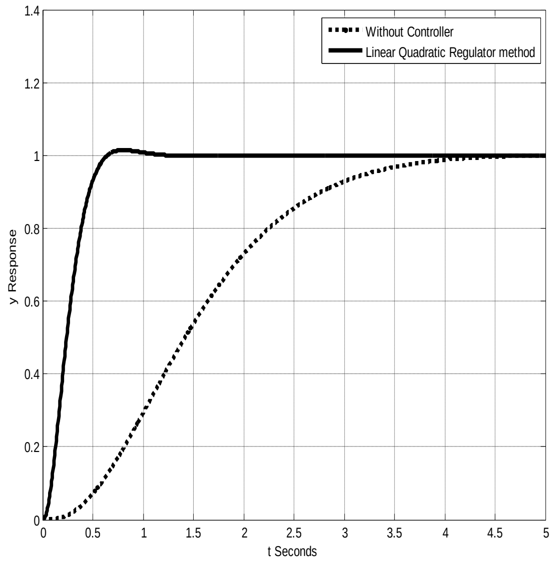

Figure 5: Unit Step Response without and with Linear Quadratic Regulator Controller

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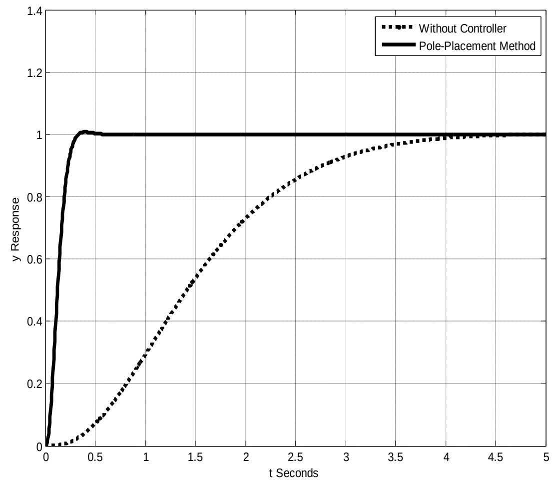

Figure 6: Unit Step Response without and with Pole Placement Method Controller

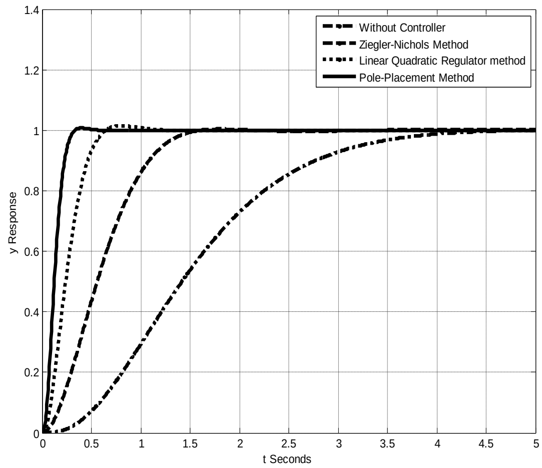

Figure 7: Combined Unit Step Responses with the Different Control Methods

Table 1: System Response Parameters for the Different Control Schemes

Parameter	Control Method			
	Without Controller	Ziegler-Nichols	Linear Quadratic Regulator	Pole-Placement
Rise Time (s)	3.0000	1.6050	0.6450	0.3350
Peak Time (s)	4.0200	1.8100	0.8000	0.4000
Overshoot (%)	0.0000	0.4000	1.4600	0.7200
Settling Time (s)	4.0000	1.3800	0.5800	0.2900

IV. CONCLUSION

The control strategies were successfully presented using the Ziegler-Nichols, Pole Placement and Linear Quadratic Regulator methods for the improved performance of the Continuously Variable Transmission System in terms of speed of operation which is its major problem. The results were also simulated successfully using MATLAB 2010a. All the methods used showed good and improved system response with the Pole-Placement method performing best with a rise time of 335milliseconds, peak time of 400milliseconds, settling time of 290 milliseconds and an overshoot of 0.72%.

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