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Performance Comparison of PID Controller on SVC and TCSC to the Transmission Line

Shamsul Aizam, Md Zarafi, Rohaiza Hamdan, Nor Anija and Nurul-Aliaa

Abstract—**In this paper the common devices where been applied at the transmission line to mitigate the voltage or current sag are Static Var Compensator (SVC) and Thyristor Controller Static Compensator (TCSC). To solve this problem a high response controller is required at the control side. One of the technique is applied the Proportional Integration Derivation (PID) controller, compared to the other controllers due to it simplicity, highly steady state response and less margin error. Here, both Flexible AC Transmission System (FACTS) devices have been applied with the same PID controller in comparing the performance response on the transmission line while having the same industrial load. In determined the response, both transfer functions have been generated and combined with PID controller feedback loop to the transfer function for locate the initial poles and zeros. By changing the poles coordinates the response will change either to have fast response or slow response.**

Keywords: PID controller, SVC, TCSC, power quality

I. Introduction

Nowadays the ability of utilities to install a power quality conditioner is very appreciated in solving power quality problem in the line. The conditioner can be placed at transmission or distribution line. Common practice used by the utility is by connecting the conditioner on the transmission line. The common power quality conditioners that been installed by the utility are Static Var Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) due to simple circuit arrangement, no transformer connection between the device to the transmission, reduce cost and easy to maintain [1]-[3]. SVC is a shunt connection to the transmission line while the TCSC is a series connection to the transmission line.

These types of conditioners are very useful in solving power quality problem due too it ability to inject the voltage for SVC or current for TCSC to compensate the power quality problem [4] when occurred on the transmission line. The major power quality problems on the transmission line are voltage sag, voltage swell, flicker, harmonic and unbalanced condition. Both devices have its own responsibility to solve power quality problem such as the SVC is voltage control that able to solve voltage sag while the TCSC is on transient stability which able to solve unbalanced condition or voltage sag on the transmission line. There are many techniques that available to control the performance of both devices in response to the power quality problem such as the conventional or modern technique. The conventional techniques are easier to develop and it has robust ability compare modern techniques [5].

The conventional techniques are Proportional Integral (PI), Proportional Derivative (PD) and Proportional Integral Derivative (PID) controller. PID controller had been selected because the settling time is faster than PI and PD controller, less percent overshoot, smaller amplitude, fast steady state [6] and the response time is less then PI which is 0.1sec [7] which this is important parameter to solve power quality problem. Nevertheless the function of pole arrangement controller is used to shift the initial poles from the right to the left of the complex diagram, in order to increase the stability of the system and damping response [7] also been applied to the controller for injecting the voltage or current referring the firing angle. In this work both devices are been applied by PID and pole arrangement controller for response performance analysis.

II. Modelling of SVC

Static VAR compensator is an electrical device in providing fast acting reactive power compensation on high voltage electricity network [8]. It provides a system automated impedance matching device where if load is too capacitive the SVC will inject the current which is proportional to reactive power and vice versa if the load is too inductive [9] and the response time can be in range of 30-60μs [10]. The general arrangement of SVC is the fixed capacitor is connected to the thyristor controlled reactor (TCR) or by thyristor-switched capacitor (TSC) with TCR [11] which shown in ‘figure 1’.

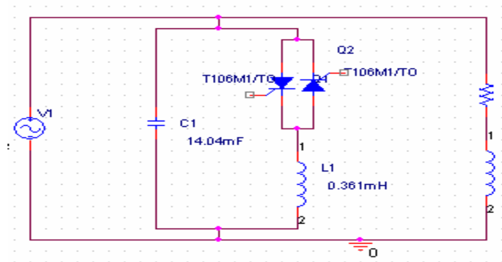

Figure 1. SVC circuit diagram

Shamsul Aizam, Md Zarafi, Rohaiza Hamdan, Nor Anija and Nurul-Aliaa are with Department of Electrical Power Engineering, Faculty of Electrical Engineering, University Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johore (email: aizam@uthm.edu.my).

In designing the PID controller, the transfer function equation from the SVC circuit must be introduced. The theory of Kirchoff Current Law has been applied to 'figure 1', where the SVC is designed in single line diagram which connected to the industrial load. The industrial load is calculated by S = 666.5K + j1154.4KVar. The C_l is a fixed capacitor connected to the thyristor T which control the operation of load that represent in R_L and L_L. The equation can be written as

$$\frac{V_o}{I_i} = \frac{s^2 LL_l + sLR_l}{s^3 LCL_l + s^2 LCR_l + s(L + L_l) + R} \tag{1}$$

Where R_l = 71.43Ω, L_l = 0.394H, C = 20μF, L=0.253H and this equation will give the initial poles at (113.0882,-34.0778 ± j561.7869) with the open loop response having highly damp and frequency where the overshoot is infinity and settling time is 0.115s and no steady state response shown in 'figure 2'.

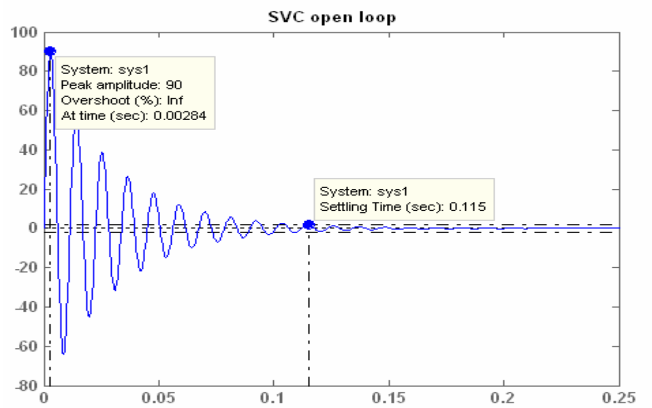

Figure 2. SVC open loop response

III. MODELLING OF TCSC

TSCS is a combination of capacitor parallel with the tyristors connected in series to the transmission line [4] where it will inject the voltage when the disturbance happen on the transmission line. TCSC is capable to provide a continuous variable capacitor by controlling the firing angle delay of the thyristor [5] and able in mitigating the sub synchronous resonance (SSR) that induced by the generator [4]-[5].

The advantage using TCSC at the transmission line is the thyristor switch allows an unlimited number of operations, exact switching instant can be select by the thyristor to reduce switching transients, no generation of harmonic an very rapid speed of response which is less then half of cycle. 'Figure 3' shows the single line diagram of TCSC.

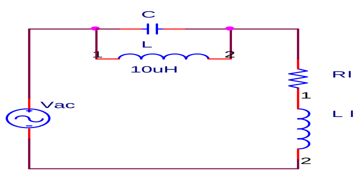

Figure 3. TCSC circuit diagram

Where the C and L represent the TCSC with R_L and L_L connected at the distribution side. The transfer function from the TCSC is shown in Equation (2) for designing the PID controller of the system.

$$\frac{V_{in}}{V_{out}} = \frac{s^3 LCL_L + s^2 R_L CL + SL_L + R_L}{s^3 LCL_L + S^2 R_L CL + S(L + L_L) + R_L} \tag{2}$$

The value for L, C, L_L and R_L are the same which the value applied for the SVC. The initial response of TSCS at the line is shown in 'figure 4' with open loop situations.

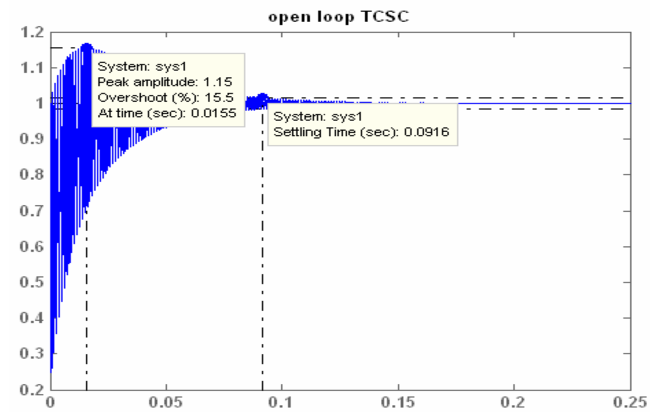

Figure 4. TCSC open loop response

'Figure 4' shows the response of the TCSC without been applied by any controller circuit. From the graph it show that the overshoot is 15.5% and the settling time is at 0.0916s that not suitable to response to the power quality time.

IV. PID CONTROLLER DESIGN AND POLE ARRANGEMENT TECHNIQUE

In designing the PID controller, the important parameter is to give fast response compare to the open loop system and with the same the steady state value to control the firing angle to the devices [5]. The transfer function of the PID controller is given by

$$K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p S + K_i}{s} \tag{3}$$

In tuning the PID, some variable of K_p, K_i or K_d have to be found. For design the PID controller, MATLAB has been used and combine the Ziegler-Nicholas [6] method to determine the values. The method proposed [5],

- From the transfer function of the devices determined the value W_u, K_{pu} and P_u by equation
- The gain for K_d, K_p and K_i are determined by K_p = 0.6(K_{pu}), T_i = 0.5($_{Pu}$), T_d = 0.125(Pu), $K_i = K_p/T_i$, $K_d = K_pT_d$

The values of K_p. K_i and K_d have been determined by referring to the suggested methods and PID controller will be connected to the devices with the feedback loop show in 'figure 5'.

The M-File Matlab window to determine the new poles location with the pole arrangement method to locate the new pole locations [12] of the controller where combine with the SVC or TCSC which have faster settling time, less overshoot, and amplitude reduce compare to original response while having the same steady state value.

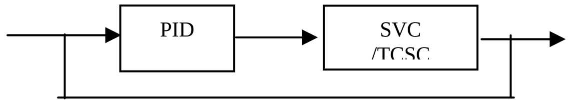

Figure 5. Complete controller circuit.

The program flows in M-File Format is shown in 'figure 6'.

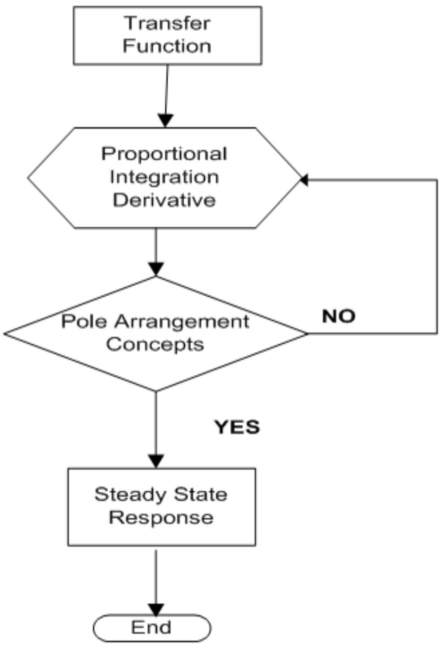

Figure 6. Flow chart of M-File

V. SIMULATION RESULT

The performance for both components with the PID controller had been simulated in MATLAB environment. 'Figure 7' shows the output for closed loop TCSC without the PID controller.

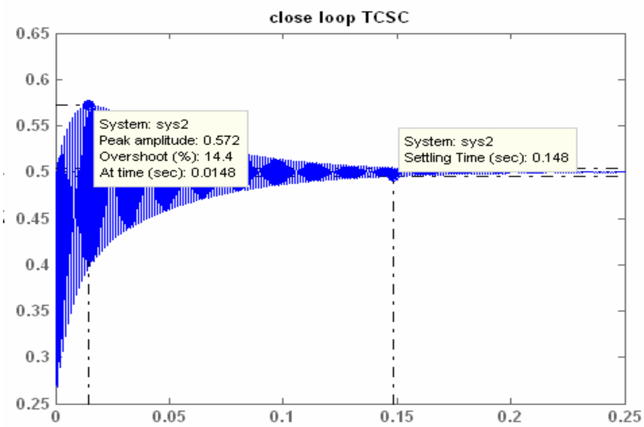

Figure 7. Closed loop TCSC

It shows that the overvoltage of the TCSC has been reduced to 14.4% compare to the open loop TCSC which is more then 50% while the settling time is having at 0.14sec which caused the controller not able to response to the power quality problem which happen less then 20ms.

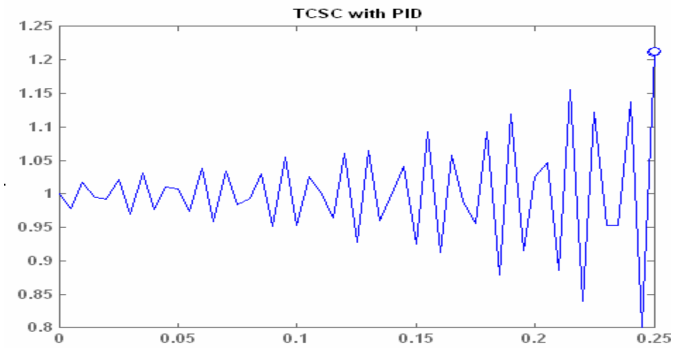

Figure 8. TCSC with PID controller

'Figure 8' shows the TCSC with PID controller. In this graph it shows the response is started at point 1 where same as the open loop response and it means the PID controller is able to maintain the response at 1. The problem on this graph is the unstable condition for the settling time due to increase oscillation when the time been increase.

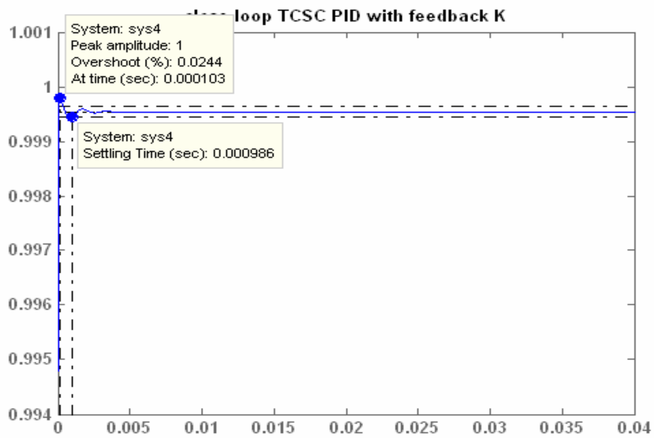

Figure 9. Closed loop TCSC PID controller with feedback

'Figure 9' shows the best response of the PID controller combine with the TCSC with the system having a feedback loop. It shows that the overshoot is reduced to 0.0244% compare to closed loop TCSC and open loop TCSC. The settling time also been reduced to less the 0.005 sec which is suitable to response the power quality. This response is set when the root locus of the feedback response give the new poles are locations at 1.0e+004 (-7.9689, -0.0985 + 0.3758i, -0.0985 - 0.3758i, -0.2458, -0.0181) due to pole arrangement application.

The same works had been done for the SVC where the graphs will show the closed loop SVC, SVC with PID and closed loop SVC with feedback loop.

'Figure 10' shows the response of closed loop SVC. In this response, the peak amplitude for the system is started at 0.997, where it not the same with the open loop response where the steady state is about 0.2 sec and also show the decaying time is larger compare to open loop system.

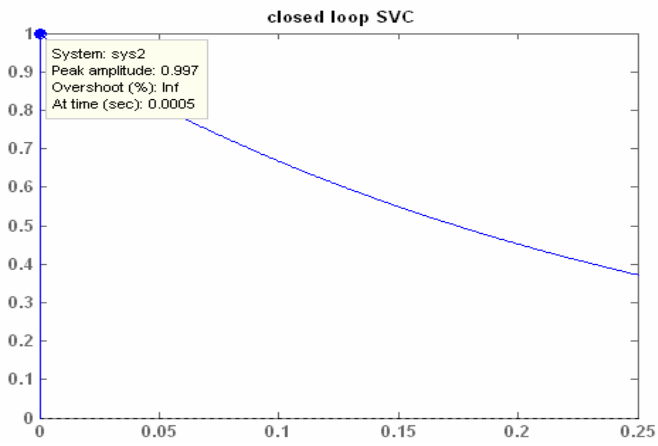

Figure 10. Closed loop SVC

For PID controller with the SVC, the response is shown in 'figure 11'. From the response the overshoot and steady state response is still high from the open loop SVC. This graph gives a conclusion that the system is not in stable condition because the magnitude of steady state is not at 0.2 sec.

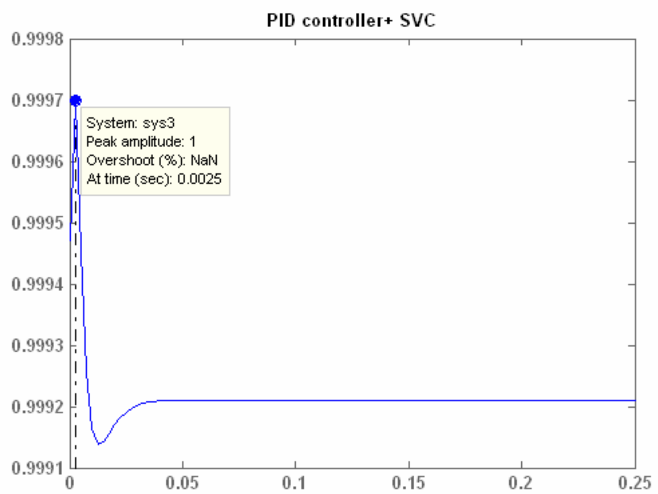

Figure 11. SVC with PID controller

A feedback loop for the PID SVC controller response is shown in 'figure 12'. At figure 12 the maximum amplitude is reduce to 0.3 compare to figure 10 and 11 that will caused the steady state response same with open loop response which is 0.2 sec. The settling time for steady state response also had been reduced to about 0.05s which is half of the time response of the open loop response. This proved that the system now is in stable condition. This response is perform when the new poles had been located at the new points which are 1.0e+002*(0,-0.8536 + 5.3749i, -0.8536 - 5.3749i, -1.1522).

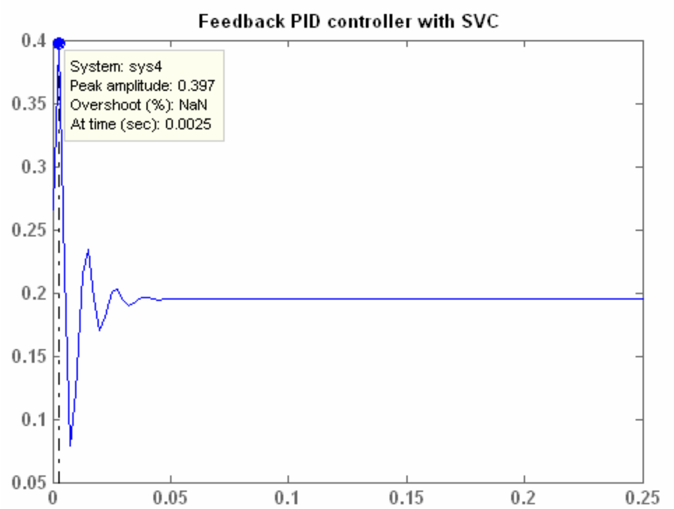

Figure 12. Closed loop TCSC PID controller with feedback

VI. Conclusion

'Table 1' shows the comparison performance of both devices at the same distribution network.

Table 1. Comparison of performance

Performance	Overshoot (%)	Peak Amplitude	Settling Time
SVC (open loop)	Inf	90	0.112s
TCSC (open loop)	15.5%	1.15	0.092s
SVC (closed loop)	NaN	0.397	0.050s
TCSC (closed loop)	0.0244%	1	0.000986s

From the table, it shows that the best devices to be apply to the transmission line with the same distribution load is the TCSC compare to the SVC due the settling time and the percentage of the overshoot that in range of the power quality response. As the conclusion the TCSC is able to solve voltage sag due to settling time response.

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