control system is shown in Fig. 17. The system has only weak tracking in the extremum regions of the reference input in which its derivative sign changes. Moreover, the control signal applied by the control system to the SMA actuator is shown in Fig. 18, and the absolute value of the rotation error over time is displayed in Fig. 19. The absolute error average for the proposed control system is 0.28 degree. It should be noted that this worth result is obtained by only training the Prandtl–Ishlinskii hysteresis model with the data of some first order reversal curves. It means that whether the generalized Prandtl–Ishlinskii model is trained by the first order reversal curves data or is trained by higher order minor loops data, the model has good prediction of the high order minor hysteresis loops of SMA actuator.

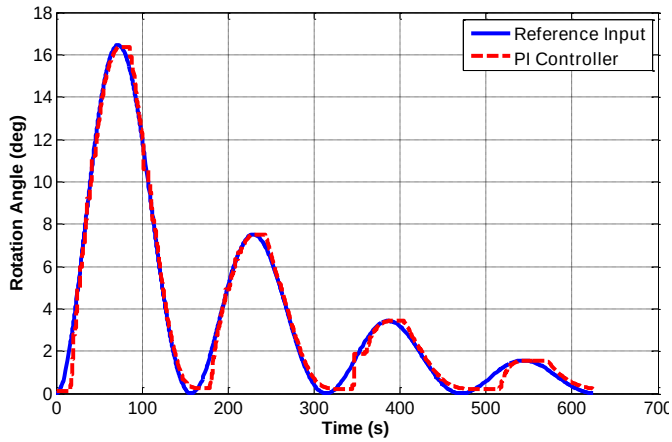

Fig. 16. Tracking control of a decaying sinusoidal wave.

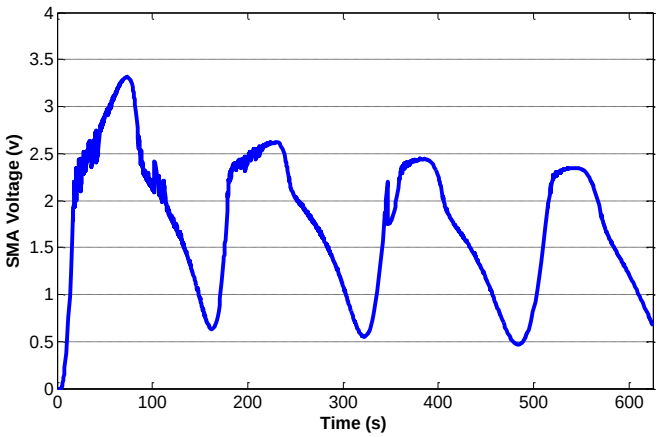

Fig. 17. SMA voltage during tracking control of a decaying sinusoidal wave.

I. Conclusion

In this paper, the generalized Prandtl–Ishlinskii model was used to model asymmetric nonlinear hysteresis behavior of Shape Memory Alloy (SMA) actuator. This model was used in a plant with a Proportional Integral (PI) controller to control a morphing wing mechanism actuated by SMA actuators. It was shown that the proposed control system has great capability in tracking square and sinusoidal trajectories and leads to low tracking error. Although the proposed control system has simple structure, it can be used for other smart structures due to the results obtained in this study. Also, it can be easily implemented for online applications and leads to good tracking error for trajectory with hysteresis loops.

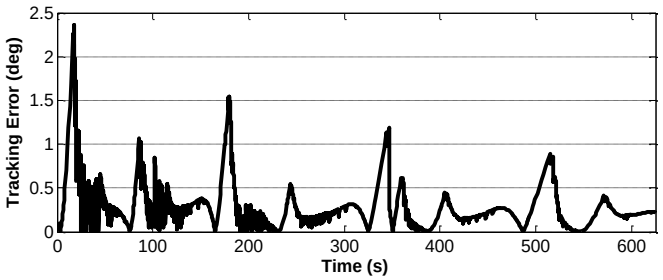

Fig. 18. Absolute of tracking error in tracking control of a decaying sinusoidal wave.

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