International Journal of Modern Developments in Engineering and Science
Volume 3, Issue 10, October 2024
https://www.ijmdes.com | ISSN (Online): 2583-3138

Comparative Overview of Factor Effecting Networked Control System Performance

Brijraj Singh Solanki*
Professor, Department of Computer Engineering, Poornima College of Engineering, Jaipur, India

Abstract**: Sensors, actuators, and controllers are all integrated into network control systems, which have growing in technology quickly. Network Control Systems (NCS) are employed in many different domains due to their low maintenance requirements, ease of installation, system cabling, and monitoring. The stability and transient performance of a networked control system (NCS) must be preserved because the addition of uncertain dynamics impairs and destabilizes system performance. Therefore, this paper presented the comparative overview of factor effecting NCS performance undergone uncertain conditions, such as disturbance. Experiment carried out in the MATLAB Simulink environment to show effectiveness of employed methodology.**

Keywords**: Transient Performance, Service Degradation attack, Kalman Filter, Networked Control System, Delay, Packet loss.**

1. Introduction

In the field of technology known as network control systems, components are connected remotely through a real-time communication network [1]. The NCS depends on the safe transfer of packets and messages through communication channels to improve overall system performance. Thanks to the rapid development of information technology, NCS has many industrial applications, such as power distribution, oil and gas power plants, water management, transportation, robotics, process industry, space vehicles, and medical treatment, among others [2].

In order to instantly control closed-loop performance in response to network cues, the author suggested a networked-predictive policy. The stability requirements, which depend on transmitting data loss and latency for the closed-loop NCS, were also discussed [3]. The stability of networked control systems is also examined by discussing the performance-degrading parameters of packet loss and random delay using a position servo system. The system in use was used to calculate the control gain and optimal performance index [4].

In network control systems, where latency and packet loss are crucial stability-controlling factors, the Bernoulli function is used to model packet loss. A few stable methods are obtained in order to illustrate the measurement quality of the specified method [5], [6]. In order to simulate stochastic packet loss and sufficient condition with asymptotic stability to capture the effect of time delay, the Lyapunov method is introduced for feedback networked control systems [7], [8].

To identify malicious activity of Industrial NCS, a random distribution procedure was used to represent the attack order in the process. Furthermore, delay is modeled using the Bernoulli distribution process. The author used a variety of attacking scenarios to analyze the performance of Industrial NCS [9].

Therefore, this paper presented the comparative overview of factor effecting NCS performance undergone uncertain conditions, such as disturbance. Experiment carried out in the MATLAB Simulink environment to show effectiveness of employed methodology.

The rest of the article is divided into the following sections: Section 2 provides an explanation of the articles that deal with the various attack types and the stability of the NCS. The problem formulation based on network uncertainty and malicious interference is presented in Section 3. The effectiveness of the approach will be covered in the fourth section. Section 5 wraps up with some last thoughts and tasks that need to be completed.

2. Background Work

The detection of an attack on non-linear networks and sensors was made possible by the introduction of an event-triggered controller scheme based on neural networks and employing a dynamic programming technique. An attack is detected when the residual surpasses a preset threshold. This approach considered a packet loss and time delay attack. The recommended methodology was identified faster than the conventional approach discussed in the literature [10], [11].

In [12], [13], the proportional integral controller, Kalman-filter, and linear quadratic Gaussian approach were used to study the effects of unwanted intrusive data in networked control systems. It has been shown that this approach considerably decreased the impact on NCS to a manageable level. To evaluate the performance metrics of the proposed system, several parameters were selected.

For NCS that experienced a DoS attack, a co-design framework for control and stabilization was introduced. The controller uses an event-based triggering strategy to update the data, and it is also disclosed that the state is periodically measured. The gain was computed for dynamic event triggering with a given sampling rate. There are fewer control updates and better performance against DoS, according to some reports

---

*Corresponding author: brijraj.eic@gmail.com

[14], [15]. For networked-connected control systems (NCCS), a predictive control was implemented to mitigate the impact of malicious attacks and network imperfections. It is claimed that the employed methodology improves transient performance and system stability across a range of packet loss values [16].

Using the predictive control approach, the performance metrics of closed-loop networked control systems subject to communication network constraints were analyzed [17]. The goal of the Linear Quadratic Regulator (LQR) technique is to improve the performance of networked systems, using a rotary inverted pendulum system as an example. In closed-loop networks, communication constraints such as packet loss and latency are considered to be unsettling. When these tactics were applied, the performance rose to the level that was desired [18], [19].

In [20], the effect of instabilities terms on NCS is investigated, and it is proposed that attacks can be announced either forward or feedback through a communication channel. The effects of these intentional attacks, process noise, and measurement noise on the overall performance of the networked control system are discussed using Kalman Filter (KF) and sufficient conditions of stability. The performance of the continuous-time networked control system is evaluated using the event-triggered scheme for channel sharing, which uses induced delay and packet loss. By examining the performance parameter and controller using event-triggered and Lyapunov functions, the efficacy of the method is illustrated [21].

A predictive controller was developed to describe how the intended approach responds to the control system. This could affect data transfer by causing a denial of service attack [22], [23]. Using an intrusion detection system, the authors have calculated the attacks introduced for wireless network management systems and validated the proposed method for stability [24].

The networked control system's packet loss and time delay problems were examined using the Bernoulli distribution process. The exponential stability condition [25] indicates that network control systems perform better when state feedback control design is incorporated. The network effects of random delay and packet loss for the nonlinear stabilization NCS problem were discussed in this article. The T-S fuzzy model was developed to model a fuzzy switched system with an unknown dynamic parameter. Exponential stability was demonstrated using the slow and fast switching dwell time methodology [26], [27]. The performance of a stochastic linear time-invariant system is maximized by minimizing the weighted cost of the linear quadratic Gaussian function. The networked system used shared communication resources and admitted scheduling policies to calculate the optimal cost [28].

Furthermore, in [29], the authors presented a comparative analysis method that showed how well the reference trajectory performed as the system parameters changed using a neural network-based controller and a traditional proportional integral controller.

The discrete-time proportional derivative controller is analyzed using a backward difference equation when random network delay and packet loss are present. In the True-Time simulator, packet loss affected the planned controlled NCS's efficacy. The findings showed that the battery consumes more energy when a packet is lost [30]. This article goes into further detail on the subject of designing H-infinity controllers for event-triggered NCS in the face of quantization and denial-of-service attacks. The time-varying Lyapunov functional method was then used to identify the necessary and sufficient conditions to guarantee the exponential stability of the NCS system in the presence of quantization and denial-of-service attacks [31].

In a paper [32], a novel method for detecting attack-induced anomalies that are particularly affected by packet losses and network delays was introduced. This technique aims to identify cyber-attacks that target networks of communication. To detect network attacks, the suggested observer-centered approach employed the detection residual. Using LMI-based techniques helps with the observer gain matrix design. The asymptotic stability of the networked system is discussed using an event-triggering methodology, and the upper bound for network delay is also established [33]. A back-stepping technique was used to create a controller for a nonlinear networked system. Numerous fuzzy logic methods are put forth to address this problem, and a nonlinear function prediction is made. The aforementioned method states that using an auxiliary signal allows one to identify the input delay [34]. The stability problem brought on by packet loss and delay can be resolved by using a switching controller. Sufficient conditions of stability were also presented using the cone-complementarity-linearization (CCL) algorithm [35], [36].

In [37], [38] robust fault detection problems in NCS with packet dropout and time-varying delay were addressed using the delta operator. The transformation of the time delay gives rise to the parameter uncertainties of the system model when the packet loss is described by the Markovian jump system. The robust fault detection filter's weight and gain matrix are determined using matrix inequality in linear form.

The maximum overshoot of the control system was limited by the author's calculation of the upper bound on packet loss and induced delay while accounting for the NCS decay rate. A set of stability requirements was also derived using Lyapunov-Krasovskii techniques [39], [40]. The packet loss and delay problems in the distributed NCS were resolved by using the transmission technique called event triggering. The controller was designed by the author to ensure that the subsystem was stable for the input signal. Determine the solution to the problem using the linear matrix inequality method and estimate the gain for bounded delay to make the system asymptotically stable [41], [42]. In the paper, the issue of fault detection in wireless NCS that is experiencing packet loss was investigated [43]. The author also considers a model class with numerous delays and interruptions. Additionally, packet loss between the actuator and controller is assumed to occur. A switching discrete time linear system with time-delay is used to represent the fault observer, and the author used a Lyapunov approach to provide a sufficient condition [44].

In [45], [46], the authors employed Markov chains to model packet loss and networked latency brought on by NCS. It is assumed that the uncertainty of the system is either increasing or decreasing. The effectiveness of the used technique was demonstrated by estimating a set of stability conditions using the Lyapunov function.

3. Problem Definition and Modeling

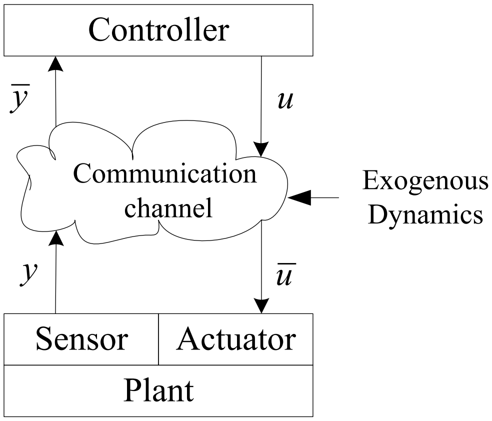

Fig. 1. Exogenous input dynamics in NCS

Figure 1 shows the block diagram for the suggested network control system. In this case, a wireless communication network is used to send the sensor's sample of the system's response to the controller. The controller determines the control signal based on the reference and sensor sample received through the communication network using a control-specific algorithm.

The communication channel transmits the calculated signal to the actuator, which controls the system to produce the desired result. An attacker can hinder the control system in any way (i.e., forward and/or feedback direction) to lower NCS performance, as has been found in many publications.

A. Plant Description

An explanation of the dynamics of a discrete linear time-invariant system with disturbance is given below:

$$x(k+1) = Ax(k) + Bu(k) + \varphi(k) \quad (1)$$

$$y(k) = Cx(k) + \omega(k) \quad (2)$$

The measurement signal is "$y(k)$", the control vector is "$u(k)$", the state vector is "$x(k)$", and A, B, C are all matrices with the proper size. Both measurement Gaussian white noise "$\omega(k)$" and process Gaussian noise "$\varphi(k)$" have zero mean and covariance, denoted by "R" and "Q."

B. Packet Loss Distribution

The controller gives the actuator instructions to control the dynamics of the system after receiving the sampled sensor signal. There is a chance of packet loss as the signal travels across the communication network. The issue of packet loss can occur in both forward and feedback directions. The distribution function that follows can be used to model packet loss [21]:

$$p(\gamma_k) = \begin{cases} p, & if\,\gamma_k = 1 \\ 1-p, & if\,\gamma_k = 0 \end{cases} \quad (3)$$

The packet loss rate can be expressed as follows. If the packet fails to arrive at instant k, then "$\gamma_k = 0$" the packet is lost at that instant and for successful arrival of packet, $\gamma_k = 1$.

4. Simulation Results

Several simulation diagrams are presented using the MATLAB Simulink environment to show the effectiveness of the suggested approach. A numerical problem with simulation results is presented in this section so that the recommended methodology can be observed.

The different simulation results are shown in Figures 2 through 5. Figure 2 present the response signal with control action along with disturbance in NCS. This demonstrates the efficacy of the suggested methodology.

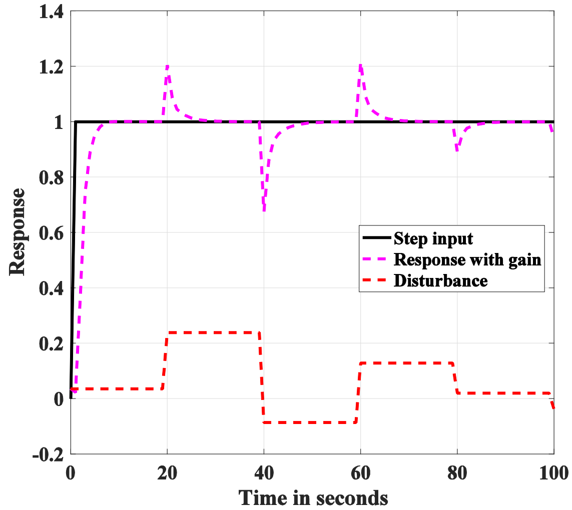

Fig. 2. Response signal with control action along with disturbance in NCS

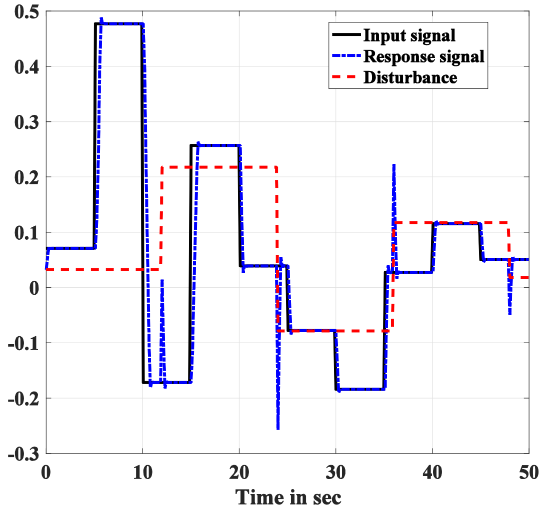

Fig. 3. Response signal along with disturbance in NCS

The simulation result as shown in figure 3 represent that response signal is tracking input signal even after disturbances is introduced in the communication channel. This shows the effectiveness of the employed methodology.

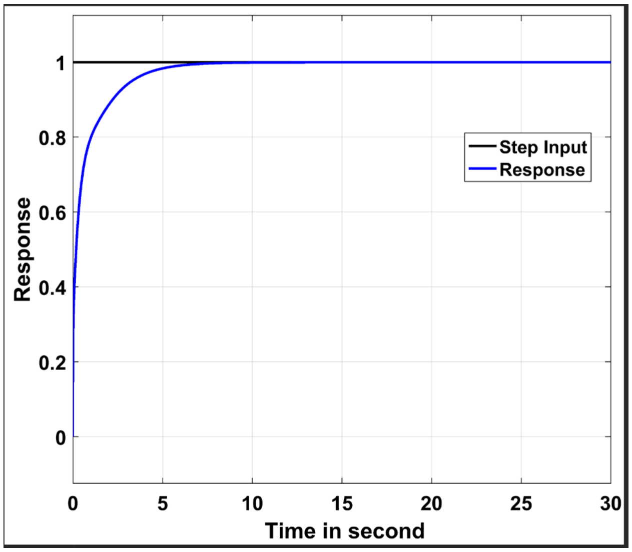

Fig. 4. Response signal without disturbance along with employed methodology

The simulation results shown in Figure 4 show how the response signal tracks the input signal following the control signal.

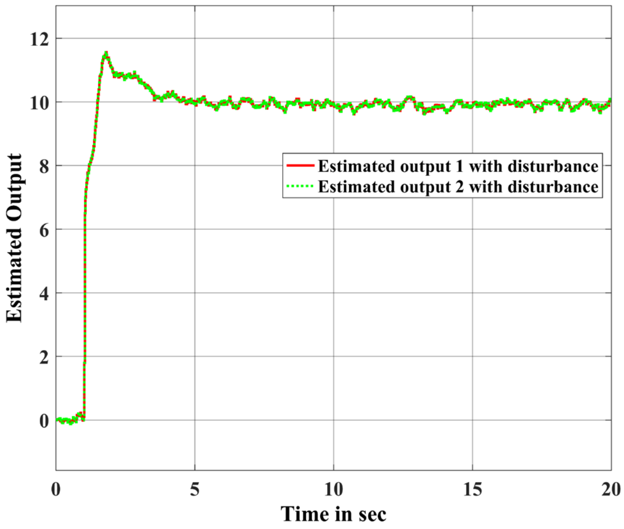

Fig. 5. Estimated output with PID control and Kalman filter with disturbance

Figure 5 simulates the generation of response signals while taking the disturbance and the PID control policy into account. Following the introduction of the disturbance and PID control policy with Kalman filter for disturbance removal, the response signal accurately tracks the step input.

5. Conclusion and Future Scope

This paper presented the comparative overview of factor effecting NCS performance undergone uncertain conditions, such as disturbance.

Figure 2 present the response signal with control action along with disturbance in NCS. This demonstrates the efficacy of the suggested methodology. The simulation result as shown in figure 3 represent that response signal is tracking input signal even after disturbances is introduced in the communication channel. This shows the effectiveness of the employed methodology. The simulation results shown in Figure 4 show how the response signal tracks the input signal following the control signal. Figure 5 simulates the generation of response signals while taking the disturbance and the PID control policy into account. Following the introduction of the disturbance and PID control policy with Kalman filter for disturbance removal, the response signal accurately tracks the step input..

Future studies will concentrate on employing the best control scheme and improving the transient performance of the nonlinear networked control system in the presence of uncertainty.

References

[1] H. Lin, H. Su, P. Shi, R. Lu, and Z. G. Wu, “Estimation and LQG Control over Unreliable Network with Acknowledgment Randomly Lost,” IEEE Trans. Cybern., vol. 47, no. 12, pp. 4074–4085, 2017.

[2] Z. Hu, K. Chen, Y. Su, F. Deng, S. Hu, and A. M. Zou, “Stochastic Analysis and Synthesis of Networked Systems with Consecutively Lost Packets,” IEEE Trans. Syst. Man, Cybern. Syst., vol. 54, no. 4, pp. 2205–2212, 2024.

[3] B. S. Solanki, “Review of Uncertain Dynamics in Networked Control System for Analysis of Stability,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 9, pp. 11–15, 2024.

[4] B. S. Solanki, “Controlled Output Feedback to Stabilize Networked Control System,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 9, pp. 1–5, 2024.

[5] M. Li, Y. Chen, X. Bin Zhang, and Y. P. Xian, “A predictive control method for networked control systems with random delay and packet dropouts,” Chinese Control Conf. CCC, vol. 2016-Augus, pp. 4372–4377, 2016.

[6] M. Assante, “Analysis of the Cyber Attack on the Ukrainian Power Grid,” SANS Ind. Control Syst. Secur. Blog, pp. 1–26, 2016.

[7] B. Singh Solanki, R. Kumawat, and S. Srinivasan, “Optimal switching control design for industrial networked control system with uncertain exogenous dynamics,” Mater. Today Proc., vol. 79, no. Part 2, pp. 286–291, 2023.

[8] G. Bhatnagar, N. Gobi, H. Aqeel, and B. S. Solanki, “Sparrow-based Differential Evolutionary Search Algorithm for Mobility Aware Energy Efficient Clustering in MANET Network,” Int. J. Intell. Syst. Appl. Eng., vol. 11, no. 8s, pp. 135–142, 2023.

[9] B. S. Solanki, “Design of an Optimal Reliable Controller for Industrial Networked Control System to Mitigate Network Imperfections,” 2022.

[10] A. Sargolzaei, K. K. Yen, M. N. Abdelghani, S. Sargolzaei, and B. Carbunar, “Resilient design of networked control systems under time delay switch attacks, application in smart grid,” IEEE Access, vol. 5, pp. 15901–15912, 2017.

[11] B. S. Solanki, R. Kumawat, and S. Srinivasan, “Averting and Mitigating the Effects of Uncertainties with Optimal Control in Industrial Networked Control System,” Proc. - 2021 IEEE Int. Symp. Smart Electron. Syst. iSES 2021, pp. 316–318, 2021.

[12] E. M. Asl, F. Hashemzadeh, M. Baradarannia, and P. Bagheri, “Observer-based controller design for a class of networked control systems with transmission delays and packet losses,” 2021 7th Int. Conf. Control. Instrum. Autom. ICCIA 2021, vol. 1, no. 2, pp. 0–5, 2021.

[13] L. Jie, Z. Ying, and F. Chunxia, “Stability Analysis for Variable Sampling Networked Control Systems with Data Packet Dropout and Partly Unknown Transition Probabilities,” Proc. 31st Chinese Control Decis. Conf. CCDC 2019, pp. 2367–2372, 2019.

[14] B. Singh and O. P. Sharma, “Analysis of Coded and Uncoded Digital Modulation Techniques,” Int. J. Electron. Commun. Technol., vol. 4, no. 4, pp. 46–48, 2013.

[15] B. Singh and O. P. Sharma, “Analysis of BER in BPSK and GMSK Employing Different Coding,” IFRSA’s Int. J. Comput., vol. 2, no. 4, pp. 736–741, 2012.

[16] Y. Sadi, S. C. Ergen, and P. Park, “Minimum energy data transmission for wireless networked control systems,” IEEE Trans. Wirel. Commun., vol. 13, no. 4, pp. 2163–2175, 2014.

[17] R. Gupta, B. S. Solanki, M. Kumar, and R. Murugan, “Detecting Malware on the Android Phones Based on Golden Jackal Optimized Support Vector Machine,” Int. J. Intell. Syst. Appl. Eng., vol. 11, no. 8s, pp. 01–07, 2023.

[18] B. S. Solanki, “Optimal Control Strategy to Analyse the Networked Control System Stability,” Int. J. Curr. Sci. Res. Rev., vol. 07, no. 09, pp. 7160–7167, 2024.

[19] Z. Lu, J. Lu, G. Ran, and F. Xu, “H∞ Filtering for Nonlinear Networked Control Systems with Mixed Random Delays and Packet Dropouts,” Proc. 31st Chinese Control Decis. Conf. CCDC 2019, no. 1, pp. 2572–2577, 2019.

[20] H. Niu, C. Bhowmick, and S. Jagannathan, “Attack Detection and Approximation in Nonlinear Networked Control Systems Using Neural Networks,” IEEE Trans. Neural Networks Learn. Syst., vol. 31, no. 1, pp. 235–245, 2020.

[21] S. P. Singh and B. S. Solanki, “A Trading Model on Block chain Smart Contracts for the Shared Energy in Brazil,” 4th Int. Conf. Emerg. Res. Electron. Comput. Sci. Technol. ICERECT 2022, pp. 1–5, 2022.

[22] A. Garcia-Santiago, J. Castaneda-Camacho, J. F. Guerrero-Castellanos, G. Mino-Aguilar, and V. Y. Ponce-Hinestroza, “Simulation Platform for a VANET Using the TrueTime Toolbox: Further Result Toward Cyber-Physical Vehicle Systems,” IEEE Veh. Technol. Conf., vol. 2018-Augus, 2018.

[23] B. S. Solanki, K. Renu, and S. Srinivasan, “Stability and Security Analysis with Identification of Attack on Industrial Networked Control System: An Overview,” Internetworking Indones. J., vol. 11, no. 2, pp. 3–8, 2019.

[24] B. S. Solanki, “Control System for Wind Power Plant,” Int. J. Sci. Dev. Res., vol. 4, no. 3, pp. 473–476, 2019.

[25] Z. Hu, F. Deng, P. Shi, and C. C. Lim, “A New Approach to Characterize Successive Packet Losses in Stochastic Networked Systems,” IEEE Trans. Syst. Man, Cybern. Syst., vol. 51, no. 1, pp. 552–560, 2021.

[26] Q. Zhang, B. Liu, and W. Huang, “Stabilization of Nonlinear Networked Switched Control Systems with Delays and Packet Losses,” Proc. 15th IEEE Conf. Ind. Electron. Appl. ICIEA 2020, pp. 332–338, 2020.

[27] B. Singh, “Solar Power Generation by PV Technology,” IRE Journals, vol. 1, no. 9, pp. 260–265, 2018.

[28] B. S. Solanki, “Analyzing the Effect of Uncertain Dynamics in Industrial Networked Control System through Control Action,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 9, pp. 20–24, 2024.

[29] J. Sun and J. Chen, “Networked predictive control for linear systems with communication delay in the feedback channel,” Stability, Control Appl. Time-Delay Syst., no. July, pp. 315–331, 2019.

[30] B. S. Solanki, R. Kumawat, and S. Srinivasan, “An Impact of Different Uncertainties and Attacks on the Performance Metrics and Stability of Industrial Control System,” in Lecture Notes in Networks and Systems, 2021, vol. 204, pp. 557–574.

[31] M. Li and Y. Chen, “Robust Tracking Control of Networked Control Systems with Communication Constraints and External Disturbance,” IEEE Trans. Ind. Electron., vol. 64, no. 5, pp. 4037–4047, 2017.

[32] K. Huang and F. Pan, “Fault Detection for Nonlinear Networked Control Systems with Sensor Saturation and Random Faults,” IEEE Access, vol. 8, pp. 92541–92551, 2020.

[33] S. Solanki, B.S., Kumawat, R., Srinivasan, “Optimized Control Function with Estimation of System Parameters Against Attack for Networked Control System,” in Intelligent Computing Techniques for Smart Energy Systems. Lecture Notes in Electrical Engineering, 2022, vol. 862, pp. 515–528.

[34] Z. H. Pang, G. P. Liu, D. Zhou, F. Hou, and D. Sun, “Two-Channel False Data Injection Attacks Against Output Tracking Control of Networked Systems,” IEEE Trans. Ind. Electron., vol. 63, no. 5, pp. 3242–3251, 2016.

[35] B. S. Solanki, “Mitigating Effect of Uncertain Exogenous Dynamics by Parametric Performance Improvement with Optimal Control Design,” Int. J. Eng. Trends Technol., vol. 70, no. 5, pp. 209–220, Jun. 2022.

[36] J. N. Singh and B. S. Solanki, “Utilization of Computational Intelligence in the Development of a Health Monitoring System for Induction Machines,” 2022 Int. Conf. Futur. Technol. INCOFT 2022, pp. 1–6, 2022.

[37] B. S. Solanki, “Stability and Performance Analysis of Networked Control System Experienced Variable Uncertain Dynamics,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 9, pp. 6–10, 2024.

[38] J. Hu, F. Zhou, and Y. Zhang, “Observer-based Event-triggered Control for a Class of Networked Control Systems under Denial of Service Attacks,” Chinese Control Conf. CCC, vol. 2022-July, pp. 959–964, 2022.

[39] M. Das et al., “Network control system applied to a large pressurized heavy water reactor,” IEEE Trans. Nucl. Sci., vol. 53, no. 5, pp. 2948–2956, 2006.

[40] B. S. Solanki, “Transient Analysis in the Networked Control System with Compensator Design,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 10, pp. 4–8, 2024.

[41] B. S. Solanki, R. Kumawat, and S. Srinivasan, “Synthesize the Effect of Intrusion and Imperfection on Networked-Connected Control System with Optimal Control Strategy,” 2021 10th Int. Conf. Inf. Autom. Sustain. ICIAFS 2021, pp. 105–110, 2021.

[42] T. Kumar, M. Sharma, and B. S. Solanki, “New Designs and Analysis of Multi-Core Photonic Crystal Fiber Using Ellipse with Different Radiuses and Angles,” in International Conference on Artificial Intelligence: Advances and Applications 2019, 2020, pp. 151–159.

[43] X. L. Zhu, X. Zhang, J. Wei, and H. Lin, “Output-Based Dynamic Event-Triggered Control for Networked Control Systems With Delays and Packet Losses Without Acknowledgements,” IEEE Trans. Automat. Contr., vol. 68, no. 12, pp. 7120–7135, 2023.

[44] B. S. Solanki, “Stabilization of Industrial Networked Control System with Transient Parameters,” Int. J. Mod. Dev. Eng. Sci., vol. 3, no. 10, pp. 9–13, 2024.

[45] T. Wang, H. Gao, and J. Qiu, “A Combined Adaptive Neural Network and Nonlinear Model Predictive Control for Multirate Networked Industrial Process Control,” IEEE Trans. Neural Networks Learn. Syst., vol. 27, no. 2, pp. 416–425, 2016.

[46] W. P. M. H. Heemels, A. R. Teel, N. Van De Wouw, and D. Nešić, “Networked control systems with communication constraints: Tradeoffs between transmission intervals, delays and performance,” IEEE Trans. Automat. Contr., vol. 55, no. 8, pp. 1781–1796, 2010.