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Review

Effects of Communication Signal Delay on the Power Grid: A Review

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Abstract: Communication plays a huge role in the operation of modern power systems. It permits a real-time monitoring coordination and control of the transmission, generation and distribution of electrical energy. As the modern grid grows towards an increased reliance on communication systems for the protection, metering and monitoring for as well as data acquisition for planning; there is a need to understand the challenge in the powers' system communication and their impact on the uninterrupted supply of electrical energy. Communication delays are one of the challenges that might affect the performance of the power system and lead to power losses and equipment damage, it is important to investigate the causes and the mitigation options available. Thus, this paper the state of arts on the cause, the effect and mitigation of communication delays in the power system. Furthermore, in this paper an analysis of different causes of the delays for different network configurations and communication systems used; a comparative analysis of different latency mitigation methods and system performance simulations of a given compensation algorithm is tested against the existing methods. The pros and cons of these control strategies are illustrated in this paper. The summary and assessment of those methods of control in this review offer scholars and utilities valuable direction-finding to design superior communication energy control systems in the future.

Keywords: smart grid; communication system; controller; operations; communication delay; mitigations; power control system

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1. Introduction

In today's world, modern power systems are becoming more and more sophisticated in identifying and making decisions and controlling various tasks that are going to be solved in different sectors such as power generation, transmission, distribution, and consumers as we find below in Figure 1. However, with the rise of technology in modern electricity, there is a growing trend in a structure that is changing and consists of efficient monitoring and regulation of each area of the electricity network. The functioning of the intelligent system has been shown to be reliable in combining efforts to improve the quality of information exchange.

In an electricity grid, communication delays arise at a number of stages, which include the signal transmission from phasor measurement unit (PMUs) to the manage centers, from the manage centers to the controllers, analog-to-digital conversion, computing on overall enter adjustable, and the phase synchronization of alerts through Global Positioning System (GPS) [1]. Such delay will have an effect on the controllers and device performance [1]. Wide control system communication networks, information sent in the shape of a package. For the most part in controlling the communication system, there are many time delays that come in the form of a packet such as latency, which is the time delay between the two sequential bits dispatched to its destination, although it also happens to be done in different communication modes [2].

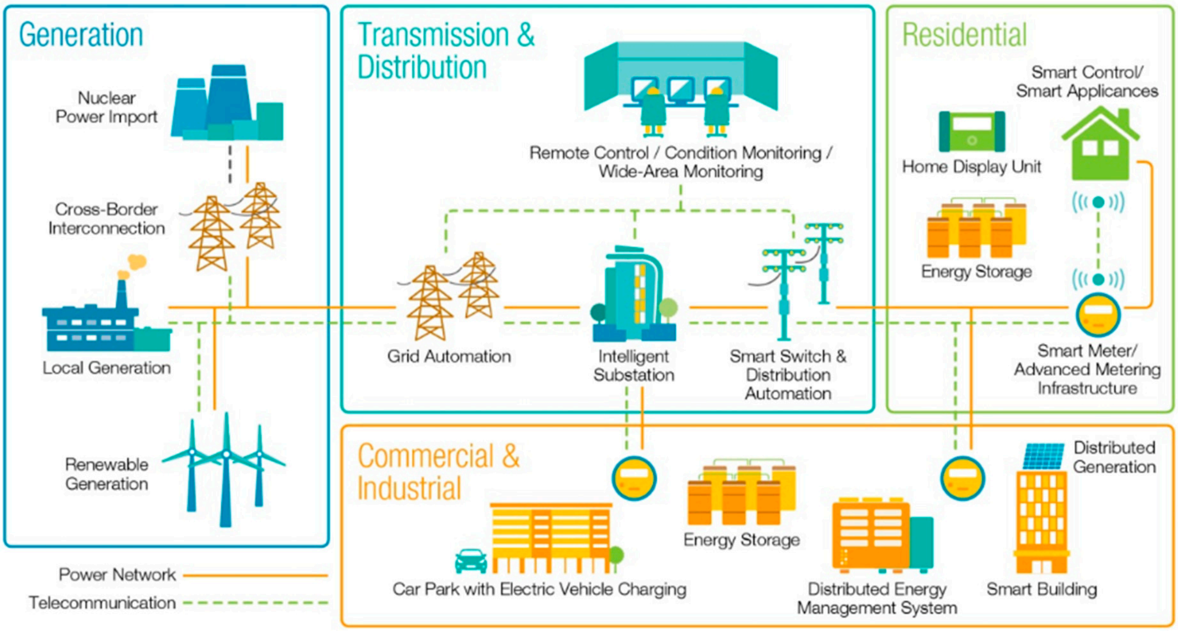

Figure 1. A comprehensive smart grid infrastructure with its components [3].

In this connection, a request is made in support of this initiative and the development of reliable telecommunications infrastructure by establishing a strong network of broadband (WAN) to feeding and customer service. WAN-based electrical equipment is based on the interconnectedness of technology in communication technology such as fiber optics, power line communication (PLC), copper-wire line, and various technologies (i.e., media communication in mobile networks such as GSM/GPRS/WiMAX/WLAN and Smart Radio). They are set up to support some monitoring/control programs such as control and information control (SCADA)/Energy Management System (EMS), Distribution System (DMS), Equipment Development System (ERP), and physical safety of equipment in large areas and broadband and capacity in closed networks.

The act of the intelligent system has been shown to be reliable in combining efforts to improve the quality of information leading to the idea of control such as relay in closing through the actual line depending on the performance of actuators, sensors, and controllers are some components of real-time communication. The other is that it is repeated in different research papers in the form of feedback. Signals are generated through a communication line to avoid costs and easy access to control, easy maintenance, and special attention is now given to the use of information technology in the control system [4].

Therefore, facilitate the supervision and regulator of electricity systems and will increase the ability to know the situation [5,6]. That is why it has been identified as one of the most important achievements of the grid, including the fact that there are many measurements and there are to communicate for control assembly as the backbone of the system. It has also been found that various measurement information, instructional signals, appeals, and up-to-date information are used among many intelligent electronic devices. Some of the papers also go back to describing the structure and size of a high-speed communication network. The amount of information from the actuators, sensors, controllers, and processes is going to focus on intelligent electronic devices (IEDs), customer advanced metering infrastructure (AMI), and distributed energy resources (DER) [7]. And it turns out that depending on the different types of components such as fiber optic communication, power line communications, and wireless technologies are the other determinants of performance as has been the case in many studies that have been revisited in the practical use of supervisory control and data acquisition (SCADA) [8–11].

The intelligent and powerful network of systems and communications continues to be taken into account, as some differences in performance depend on the architecture, at the current level, the power grid is characterized by a cyber-physical system (CPS), which includes the physical process, sensor/actuator, network, control centers, and information that indicates the disturbance information depending on the position or function [3,8] The use of each category is possible, and information flows between all levels, as they only work together [12]. As there are delays in communication and cyber-attacks appear in many and varied ways, for example, there is a basic description of it is to use power lines and direct/indirect electricity where no network user is installed. As the various interactions of the intelligent grid include the physical, functional, and commercial complementarity through the communication network to exchange information, the attacks are larger than those listed in Table 1. However, in this table, we show the latency and the normal surface area that has the potential to be affected by modern power systems that are reviewed as a baseline to determine the domain and the type of normal attack and as we will see later in order to take precautionary measures against the grid [8]. According to Wei L. et al. [9], the main attacks are most likely due to the technology being used, and the communication delay shows that it has a part to be counted as shown in Table 2. As exposed in Table 2, the SCADA, control system, and State estimator there is a communication delay, but you see in the attacks there are other major loopholes such as service denial of service (DoS), false data injection attack (FDIA) [8,13] robbery [14], the introduction of destructive programs or worms, and damage to the electrical system such as attacking 14 destructive devices [15].

Table 1. The difference between communication delays and cyber-attack in power systems [8].

	Transmission System	Distribution System	Device	System	Cyber Attack	Delay
Data concentrator (DC)	√	√		√	FDIA	√
SCADA	√	√		√	FDIA/DOS	
Control system	√		√	√	FDIA/DOS	
State estimator	√			√	FDIA	
Communication channel	√	√		√	DOS	√
Power market	√			√	FDIA/DOS	√
Remote Terminal Unit (RTU)	√	√			FDIA/DOS	√
Phasor Measurement Unit (PMU)	√	√			FDIA	√
Programmable Logic Controller (PLC)	√	√			FDIA	√
Advanced Meter Infrastructure (AMI)		√			FDIA	
Intelligent Electronic Device (IED)		√			FDIA	

Recently, the suggestion that follow-up assessments are due to delays in some effects of power system levels as described in these papers [16,17]. There are also different ways to control, to evaluate the communication delay in the AGC system discussed in [18]. Security-related delayed system measurements between equipment and controller [14,18]. Heydari et al. have shown that communication in delays affects microgrid island and continue with the second inspection that took place the survey was conducted with a small sample [19,20]. Some researchers showed one of the ways in which literature only assessed its power delayed check for the second check (e.g., [21]) and others (e.g., [22]) on the full line of the power of the system, both are small-scale signals. There are also indications of the effects of testing delays on the distribution system state estimation (DSSE) were investigated using Monte Carlo (MC) analysis in [23,24] are evaluated, using a well-defined weighted least squares (WLS) the weight of the matrix, in [25], however, to the knowledge of the authors, it has never been established as an undoubted source for growth the analytical expression for calculating the final state estimation (SE) is undoubtedly related to the shock from the communication. As Hasan Ali has highlighted in the lines of analysis in various power system activities, namely in view of the delay in communication, it has been shown to be necessary to dramatically reduce delays to secure the line to be firm. However, the practical experiences of the rope you have calm in many cases ignoring the effects of communication delays as they are categorized [26–29]. The stable security system has been restored to the role of telecommunications delays, while telecommunications delays are calculated in the diagrams [8,18,30].

The results of this study show that ignoring the effects of communication can not only undermine control performance, but also can disrupt the entire system in some cases. The time it takes to send data from a dimension position to a switching center or data concentrator, as well as the period it takes to relay this information to command devices, exists referred to as communication delay or latency in a wide-area control system [31]. This can give insight into communication on methods and technology for analyzing and overcoming delay-based problems in the smart grid. Interval delays may want to stand up in energy systems for not the same motives, and their magnitudes depend on the communique link form, for example, cellular phone strains, fiber-optics, and satellites. Delays in communication can take place at any point in a control system. The addition of a time delay to a response circle destabilizes the system and decreases the damping efficiency or quality of the control actions [14,32,33].

This paper summarizes the state of affairs in the research and summarizes the findings in the event of a delay in communication in the management of security in the power system. Based on the results of our various studies, we make new contributions in the following ways:

- Indicate the causes and effects of communication delays in the power system and research activities in these specific areas.
- Develop a plan to reduce or compensate strategies for the impact of communication delays in the power system.
- To test the simulation of the performance of a given algorithm, its performance is compared to other development methods tested on the widely used system in the literature.
- Examines how the system can be delayed in dealing with cyber-attacks that can cause delays.
- Therefore, this review aims to demonstrate the status of the problem and to show a new research direction provided can be a guideline for different researchers.

The rest of the review paper is prepared as follows: Section 2 discusses previous and ongoing related works. Section 3 deals with contracts and robust telecommunications analytics based on the power control system with Network-Induced Delay and Packet Dropout. Section 4 outlines the different types of mitigation techniques. Section 5, which is devoted to the main results and discussion of the results of the literature review. In Section 6, Barriers to communication latency over unstable smart grids and network control are briefed. Lastly, in Section 7, conclusions and remarks are finished for this paper.

2. Previous and Current Related Works

Nowadays, it has been pointed out that the proposed method of strengthening the system for monitoring the flow of information and external disturbances has continued to be demonstrated in a variety of ways to address delays and loss of information. The current user interface is based on a modified switch that is checked to stop the system from connecting in an early manner. It has been shown that the suggested method strengthens the network monitoring system related to information flow and external disturbance. In reference [34], a T-S fuzzy network-based investigation was conducted using a delayed fuzzy control and was not performed by a well-positioned controller. In reference [35], a major innovation in the change in control time has been introduced based on time delays and loss in radio packages. In [36], the decentralization process—is driven by the control over the research done on a system with a different structure. In [37], the reduced NCS program is provided in view of communication delays. The solutions were used to reduce the integration of multiple regions into the power grid. A brief overview of NCSs is provided by reference [38] on system configuration, complex problems, and how they are used [39].

In reference [40], a time-varying algorithm for measuring the power equal to the sensor side has been proposed to lead to a closed-loop system. The algorithm was successfully introducing zoom measurements. Full description of the different types of control techniques provided by reference [41]. The results of the network control and the delay and loss of packet information were reviewed in Reference [42], In Reference [43] how to delay the time in a large system that connects the wiring harnesses to the wiring harnesses, the new selection and control method is provided by reference [44], a first state-space model was established, in which the error was monitored, and the state variables were combined and implemented [45]. The good comparison problem in the network control has been lost with the planning to store information in detail as shown by the researchers [24]. In [46], the Slide Mode Controller (SMC) issue for NCSs was concerned with the stochastic partial rotation, better known as Markov, or object rotation, and with unplanned measurements [39]. In [47], for which a model for the removal of a model, it is provided for a system that is compatible with thinking about data loss and communication delays. Therefore, it is found that in [47] the communication load can be significantly reduced, and the useful energy can be greatly improved while maintaining the performance of H∞. The pendulum fluctuates with a single power line system controlled by a sensor network that does not have wires provided to indicate the performance of a given self-triggered sampling scheme (STS).

The summary of NCSs in Ref. [38] goes on to address a variety of issues. According to the modified system problem, the external system connects to the network with the errors investigated in [48]. Wei Y and colleagues [49], showed the difficulty of delay-based severity is the main reason for controlling Output Solutions (SOF) control for indefinite phase T-S fuzzy (FA). In return, the issue of unstable comparisons of the state through communication and the loss of the park has been solved in [50]. The study on reduced species and the type of filtration that was provided by reference [51] on industrial CPS, was explained by different genders. In Ref. [52], the authors addressing the concerns of many sections, which are based on information from cyber-attacks, designed to improve ICS security. He described the new Lyapunov-Krasovskii method, shown in the rapid analysis of the analysis of a large closed-loop system. Moreover, an investigation into the controlled and reduced type of filtering on CPSs was defined by the comparative data provided by the Ref. [53]. In [54], the authors were interested in the exchange of information between the integrated microgrid and the second-hand controllers in the management of the microgrid. Liu S et al. They continued to show the effects of delayed communication on the second microgrid control island and several generators were reduced. They conclude that the A gain scheduling approach (GS) is also proposed to pay late compensation by contacting the secondary frequency control. In Ref. [55] the authors suggested the control of droop to two new secondary control system (SCSs) monitoring programs were discussed to address the issue: (1) a model predictive controller (MPC); and (2) a Smith predictor-based controller [55]. However, even if they do, they are still trying to figure it out on the delay of different periods in the microgrids (MGs).

Yan H et al. showed that the method of comparing the microgrid method with the delay. They continue to make it clear that Lyapunov's method is used to analyze functional stability. Finally, the expected sliding mode control (SMC) strategies are confirmed by comparative microgrid studies and delays problems [16]. In [56], the authors investigated the robust problem of the network control system. In [57] focused on solving the problem of sliding on continuous-flow control systems without a control system line. They keep in mind the delay in importing and the lack of high-speed communication including the time of transmission and the protocol being sent. Although research papers are available, they continue to address the issue of delays and delays. There is a team of researchers consisting of Fang F et al. [58], in their achievements and in the fact that the problem of fault tolerance-measured-data H∞ controls the network control system and the delay and the fault of the actuator. In [59] have demonstrated an effective way to model-free adaptive control (MFAC), which uses pseudo-partial (PPD) materials to connect unconnected power lines, considering WADC requirements and system disruptions are required to eliminate disruption at the inter-area oscillation for a wind farm [59,60]. In addition, to compensate for the delays of communication in the wide-area measurement system (WAMS), the compensation for delay coordination and adaptive delay compensator (ADC) is used to pay for constant and variable delay. In addition, to compensate for communication delays in a wide-area measurement system (WAMS), an adaptive delay compensator (ADC) is active to repay both continuous and adjustable delays [59–61].

In reference [16,62], the authors discussed the effects of time-delays in WAMS-based monitoring activities on the performance of the system [63]. Molina-Cabrera A et al. demonstrated the ETDC, which uses a delay method to differentiate a line delay method rather than a deadline; moreover, the ETDC uses real-time signals and how to send measurements to WAMS that builds a closed-loop database system [62]. In [64], the authors deliberated the combination of power control and communication in network control which yields interesting results in the design, and they reported that because the analytical approach is not feasible in the form of a robust system, the paper also prepares a new general method for calculating the system's eigenvalues and various delays that cannot be explained by the analysis of possible objects. In Ref. [65], the authors discussed the LMI method to better compensate for the delay caused by the delay and to provide the desired performance [39]. The authors of [66] used the NN method to accurately compare the TDS attack in real-time and to assess the delay in the NCS system to see its safety effects on two power systems. In [21], the authors provide an analysis of a one-time load control program, the main way to maintain the safety and security of the energy system. Moreover, Markov's idea is the basis on which they set up a model to better explain how to combat inaccuracies in measurement and external disturbances. Then, a new fractional-order global sliding mode control scheme containing fractional-order terms on the sliding surface is accepted to improve the robustness of load frequency control. In [67], the authors gave a new idea of calculation, and the statistics given on this structure were given to illustrate the positive effects of calculation. The above development can be grouped in table form according to the region/network/criteria as follows.

Table 2 summarizes information on how to distribute the paper in various sections published since 2015. The main focus of the research in this section was on delay-based networks [39]. That is why it has been shown that the difference between the tasks reported in the research has been varied depending on the safety approach, the model-based approach, and the model-based approach including the initiation of the delay. In addition, some summaries have shown that there are various ways to combat delays in communication based on design or topology as they are built in three types, as has been shown in some research papers presented in Summary in Table 3.

In the past and in the present research, it has been shown that some advantages and disadvantages of problem-solving, are also indicative of weakness. Table 4 summarizes results based on current events and compares them to their pros and cons. Recent papers have found that it solves many problems in terms of efficiency and security.

Table 2. Summary of discussions on control system development since 2015.

S. No.	Reference No.	Parameter/Area/Network
1	[4,14–16,18,25,30,31,33,35–38,46]	Model/Sampling Based Networks
2	[21,22,24,36,40,42,43,48,55,58,67–69]	Stability Analysis/Approach
3	[9,14–16,18,20,22,26–28,31,33–37,39,41–63]	Time Delay/Fault/Track/Detection/Packet Loss
4	[4,11,12,17,25,26,30–32,34,39,41,42,50,52,54,56,64]	Internet/Communication Based Multi-Rate Control Networks
5	[16,17]	Distributed Networked Control Approach
6	[17,25,28,32,37,60,65]	Event Based Networks/Interactive Networks
7	[59,61,62,70–74]	Compensate network/Compensation strategies

Table 3. Summary of different types of topological discussions.

S. No.	Reference No.	NCS Topology
1	[12,17,30,33,41,44]	Centralized Topology
2	[16,36–38,64,67,75]	Decentralized Topology
3	[37,38,53,55–58,64,66,68,70,71,76]	Distributed Topology

Table 4. Comparison of current activities with previous activities.

	Present Work		Previous Work	
S. No.	**Pros**	**Cons**	**Pros**	**Cons**
1	Minimizing outages and their effects	Overhead costs	It is easy to implement	Network model is limited
2	Automatic processes and user controls	Expensive	Capacity	The method can be expensive
3	Incorporate more renewable energy resources	Time-consuming	Various network configurations can be easily analyzed	Some method limits inaccuracies
4	Communication technologies and autonomous networks	Hacks or other malware attacks	Cost effective, reliable, suitable for establishing back bone communication infrastructure	Low bandwidth
5	Corporate IT departments and Safety factor increases	Complexity and congestion	Closing the gap between periodic tests	
6	Asset management and High channel capacity, data rates	Low range of capacities for distributed generation	Introduction of LAN in substations and interactive networks	
7	Rapid installation and wide range of applications		Merging protection and SCADA networks	
8	Effective reduction of system complexity		Basic data collection and long delay	

3. A Robust Telecommunications Analysis Based on the Power of the Control System and the Network Caused by the Delay and the Packet Dropout

In the study, there were many delays caused by the network [74,77]. In Ref. [77], four main types of delay are discussed, namely: (a) the model of constant delay, (b) the model of extreme delay, (c) the Markov chain model, and (d) the Markov model. The reasons for this type of delay are in a low speed, network speed, and the protocol sent [19]. There are two types of delay, especially (i) sensor for delay controllers and (ii) controller delay for the actuator. Because network latency is due to network connectivity, it is sometimes fluctuating, unexpected, and the upper boundary is unknown. As a result, the delay caused by the network is usually done as a time delay between [69,78] and a Markov network with a known transitional probability, a probability of a partial transition, and an arbitrary change [77]. As declared, in reference to [79], network delays have been identified as a reason to undermine the functioning of the system or possibly as a reason for insecurity. In [39,80] authors proposed an algorithm based on a gradual push of money to address Electronic Data Processing in a way that is reduced to a communication network with different topology and communication latency. The proposed algorithm is allowed to solve Electronic Data Processing if different communication networks are connected together. There are some systems where communication delays can have a positive impact on system performance, as described in [39,81]. In Ref. [82] the authors asked for an LMI method to identify the two-way static solution provided by the gain controller to compensate for delays and a well-planned network and provide audit performance. Table 5 shows the statistical delays in the various studies conducted in the reference paper. The maximum delay to be assessed is 500 ms [62,83].

The data packet has dropped the problem and is a major issue, depending on the shipping method. Broadband and a lot of information are sent to one line responsible for this defect [39]. Numerous studies have examined losses in network control [47,84,85]. These difficulties often occur due to the exchange of information between different devices, which degrades performance and can disrupt the system. Due to numerous vehicles, the loss of parking information is also a major concern [39]. Basically, the effects of dropping out of school are also known as Bernoulli or Markov. In many communication networks, various data packets are slow to arrive, providing times when the previously sent data packet can reach its destination later [42,43]. Tables 5 and 6 show the statistical data for the loss of the pack considered in the various studies in the literature. The estimated rate of park loss is 80% in the definition [25,39].

Table 5. Delay data measured in dissimilar studies.

Reference No.	Type of Delay	Delay/Delay Range (in ms)	Merits
[81] (2019)	Random Delay	0 to 100	Secure the system
[86] (2020)	Random Delay	30 to 300	Maintain operational stability
[87] (2018)	Network-Induced Time Delay	0 to 700	Identify the distribution of time delay
[88] (2021)	Constant Delay	300 and 500	Improving the stability of the power system
[62] (2021)	Time-Varying Delay	100 to 500	Increases the transfer capabilities in tie
[89] (2021)	Variable Delay	50 to 100	attenuate the influence

Table 6. Packet loss degree measured in different studies.

Reference No.	Loss Rate/Loss Rate Range (in %)
[90] (2014)	0 to 5
[42] (2016)	20 to 70
[44] (2016)	20 to 40
[91] (2020)	0.05 to 1.5

4. Compensation for Electricity-Based Communication and Network Latency

Communication delays may lead to insecurity of communication-patrol frameworks. Expanding inquiries about efforts have been committed to planning progress control strategies to overcome the impacts of network-induced delays [70]. In this segment, various switch strategies have been presented to compensate for the impacts of delay caused by the network within the power control framework.

4.1. Evaluations between Direct and Indirect Methods

Modeling the uncertainties, in terms of time delay, packet loss probability, queue length, and throughput is greatly highlighted to confirm that communication infrastructure remains robust under malicious attack [92]. So, it is essential to build an appropriate communication infrastructure, otherwise, the system may introduce potential degradation of dynamic and static performance of power system and result in system instability [92,93]. In LFC, due to the use of open communication infrastructure and phasor measurement units (PMU) in the wide-area monitoring systems (WAMS), communication delays have become assured and raise concerns about the system's steady-state and dynamic response [61,92,94].

According to the data collected by the researchers in Table 7 with respect to the delay initiated in the control activities carried out, there are two types of delays that coincide with the power system. The first is a direct method based on the tracking of eigenvalues. However, the direct method can only solve delays in the system [95,96] and the method cannot withstand the delay [88,92]. The second and most direct method is based on H-infinity robust synthesis, Lyapunov's unstable theory, and matrix equilibrium (LMIs) technique for controlling the delay of the controller [88,92,97]. Although limited, these skills can solve a variety of problems and delay those [68,75,81,98].

Table 7. Assessments between direct and indirect methods.

Methods	Calculation Load	Cooperativeness	Delay Type	Application
Direct	High	Low	Constant	[80] (2019) LFC, [96] (2015) WADC
Indirect	Medium	Medium	Constant and time varying	[99] (2020), [100] (2019) LFC, [75] (2017) LFC with DDC, [98] (2014) WADC

On the one hand, in the case of the stochastic switching method, both the forces of delay due to the delay and of the power system are considered [70,101]. The ongoing interaction between the communication network and the power system is well-considered and comparable [70]. On the contrary, the expected system method shows the optimal value using the delayed data due to the network. This method is used more easily than before. Just as the delay in communication is not too late, it is serious that a quiet analysis method of communication based on an energy control system is essential. However, so far only a handful of cases has been reported. Therefore, research efforts are needed to conduct a reliable and reliable investigation of the effectiveness of the communication power control system.

4.2. Nonlinear Control

In addition to the adaptive self-tuning control method, there are still many important non-linear monitoring methods to address malfunctions in power systems, including the sliding mode control (SMC), fuzzy logic (FL) control method, network control (NN) methods, and hybrid system methods [70,95].

4.2.1. Sliding Mode Control

SMC is a variable structure control method that drives and then maintains the system trajectory within a particular neighborhood of a sliding surface [16,70,74,95]. The generally, there are two steps to designing a sliding mode controller.

- Step 1: Describes the switching work: the switching work is planned to protect the framework while sliding in a dynamic manner.
- Step 2: Define a switched control law: the switched control law is designed to move the framework state vector to the sliding mode and maintain it once it arrives.

Sliding mode control has proven to be an efficient approach to compensate for power systems [70]. To compensate for the delay in communication, SMC monitoring is based on broad areas and has been monitored to ensure that WADC does not misinterpret communication delays [52,70]. In terms of latency indefinitely, it was discovered that residing on a slippery slope due to the lower and upper slopes causes endless delay [102]. Only fuzzy control measures have been taken, except for the fuzzy-based integral sliding mode load frequency control system (FISMLFC) which is required for many parts of the integrated Wind Farming (WF) system [26,95].

4.2.2. Fuzzy Logic Control

Planning an FL controller incorporates three stages:

- Step 1: Fuzzily (Make membership work): this step includes mapping numerical input parameters to fuzzy factors for a characterized membership work.
- Step 2: Indicate the run the show table: this alludes to making a run the show table to determine all combinations of input signals and compare output signals for these input signals.
- Step 3: Defuzzily the outcomes: it includes producing numerical input values which can be utilized as control inputs of a control framework, based on the outputs of the fuzzy rules.

FL controllers have been broadly utilized to handle vulnerabilities in control frameworks. In [75], an FL wide-area damping controller with moving membership capacities is proposed to compensate for the expansive latency included within the transmission of wide-area estimation signals. In [31], both time delay and uncertainties in measurements in the fuzzy type-2 WADC [31]. In [103], a new direction was established by the T-S Fuzzy Control System (TSFC) and the delayed separation time in many parts of the system is applied for the load-frequency control of a three-area electrical interconnected power system to enhance the system stability under uncertain disturbances [70,95].

4.2.3. Neural Network Control

Understanding an artificial issue without a numerical demonstration of a real framework, as it were, by utilizing the interconnects between the neurons within the various layers of each framework is part of planning a NN controller. Association of neurons can be modified in its structure to clearly demonstrate the relationship between input signals and their valid fields. Learning gives NN controllers the capacity to infer subjective straight or nonlinear mapping [66]. Because of this feature, NN-based control can be used to improve the resilience of control frameworks and address communication link weaknesses. The use of NN-based wide-area damping controllers to adjust for wide range of communication delays was investigated in [104]. Wang S. et al. [71], neural network approximate-based feedback adaptive quantized control protocol based on k-filter observer is proposed to reduce the estimated error and external disturbances resulted from multi-machine excitation system.

4.2.4. Comparisons of Remuneration Approaches

Table 8 summarizes a comparison of these control strategies utilized to compensate for network-induced delays in communications-based frameworks within the literature. As can be seen from the table, the nonlinear control strategy is generally autonomous of the framework shown and has high robustness to parameter vulnerability and unsettling influences, particularly ETDC, MFAC, and NN. Be that as it may, due to the plan of these controllers, preparing the LKF, FL, and NN controllers involve a huge sum of estimation information. Planning H_2/H_∞ , SMC, and other model-based strong controllers are moderately direct but have constrained vigor to parameter instability compared to non-linear controllers. Luckily, most of these controllers can be utilized to compensate for both deterministic and arbitrary arranged delays. As for the structure, these recompense strategies have been connected within the interconnected electricity framework control, such as WAMS, WAC and WAMC, whilst their purposes in microgrids are right now within the infants as most of the current microgrids are still in-lab demonstration projects and have not been broadly connected within the real world. In any case, functions of these manipulation techniques in microgrids vitality administration and manipulation have been drawing in quickly expanding consideration as the critical requirement for smart networks around the world.

Table 9 provides a comparison of experimental analysis of various traditional and associate classification techniques. Through the analysis of the table below, it shows the indicators of the performance of the algorithm for different power systems. We have compared different techniques, and they have different criteria in the system, for example accuracy, consistent, scalable and efficient reduction of overshoot. Many research results have shown that smart building techniques are more effective and predictable than traditional techniques. In the case of strategies such as ETDC + MPC, DOF-WADC, FLC and DOFC they are being used to assess performance, in fact, and F-scale. The comparative analysis concluded that ETDC + MPC and DOFC are superior to other techniques.

Table 8. Evaluations between direct and indirect methods.

Detail Modelling Techniques	Model Dependence	Robustness	Design Difficulty	Delay Type	Applications	Main Contribution
(2016) (MPC) and Smith predictor-based controller	Low	Medium	Low	Deterministic and random	[55] Microgrid	Stability analysis based on small-signal
(2016) H_2/H_∞ synthesis controller	High	Low	High	Deterministic and random	[61] WAMS	Considers model of time delays
(2018) LKF	High	High	High	Deterministic and random	[22] WAPS	Stability analysis
(2018) LMIs	Medium	Medium	Medium	Deterministic and random	[69] WADC	Optimization-based information sharing
(2019) Sliding mode control (SMC)	High	Medium	High	Deterministic and random	[16] Microgrid	Stability enhancement
(2020) Fuzzy logic	Low	Low	High	Deterministic and random	[94] WAMS	Calculate delay margins
(2020) T-S Fuzzy control (TSFC)	High	Medium	High	Deterministic and random	[68] LFC	High Stability system
(2016) Model-free adaptive control (MFAC)	High	Medium	High	Deterministic and random	[43] WADC	Calculate delay margins delays Scenarios.
(2021) Enhanced Time Delay Compensator (ETDC)	High	High	High	Deterministic and random	[62] WAMS, WAC, WAMC	Calculate reduction of overshoot (almost 39%)
(2021) Analytical approach and Optimal control gain	Medium	Low	High	Deterministic and random	[105] WAMSs	Design robustness of a small-signal stability
(2021) Neural network control and new Fractional-Order Global Sliding Mode Control	Medium	High	High	Deterministic and random	[71] LFC, [21] multi-area power system LFC	Compensate approximation error and The stability and stabilization

Table 9. Comparative analysis of different algorithms.

Techniques	Application Size	Threshold Parameters Applied	Compared with	Results
[106] SDC (2013)	IEEE 50-generator test system	$T_d = 0.1$ s to 0.7 s $f = 0.1$ Hz to 2.0 Hz $\rho = 0.0315,\ 0.0246,$ 0.016 0.0077	Without SDC	More time efficient and faster than without SDC
[107] DD-WADC and DOF-WADC (2016)	IEEE benchmark system (WADC)	$T_d = 800$ ms to 250 ms $f = 0.5777$ Hz $\rho = 0.0152$	PC-WADC	More time efficient and faster than PC-WADC. Even under the effect of the time-varying delay of the wide-area communication network, it knows how to still maintain a good damping performance.
[108] BA and BESS (2019)	Java 500 kV Indonesian grid (WAMC)	$T_d = 100$ ms to 700 ms $f = 0.6567$ Hz $\rho = 0.0569$	POD and BESS	Higher accuracy and faster than BESS, highly competitive with POD and BESS
[1] FLC (2019)	IEEE nine bus power system (WAMS)	$T_d = 0$ ms to 700 ms $f = 0.5777$ Hz $\rho = 0.0152$	MPM	More consistent and highly effective at classification and has minimize the impact of delay in positioning on the power structure of the Hybrid system.
[109] DOFC (2021)	Four Machine Two-Area Power System (WADC)	$T_d = 100$ ms $f = 0.6567$ Hz $\rho = 0.0823$	PID	Better performance than PID, Execution time is less.
[62] ETDC + MPC (2021)	Kundur's 2-area test system (WAMS)	$T_d = 100$ ms to 500 ms $f = 0.598$ Hz $\rho = 0.0205$	SPB + MPC	More accurate, scalable and efficient reduction of overshoot (about 39%) implies less stress over the thermal limits and less impact of isolation due to protective actions.

5. Results and Discussion of the Literature Reviewed

In this section we take a look at an assessment that leads to a variety of results caused by communication delays. First, we look at the evaluation we have done in MATLAB/Simulink software, the last we look at the evaluation together and it is the results from different researchers.

5.1. IEEJ West 10-Machine Model System Results

To analyze the communication delay in the IEEJ West 10-machine model system (60 Hz) [91] is under review (as shown in Figure 2). According to this system the Japanese model consists of 10 generators, G 1 to G10, Generator G 10 is considered a swing generator. In this work, five braking resistors are installed at the terminal buses of generators G1, G4–G6, and G10 for the stabilization of the overall system. Therefore, it is essential to notice that every single system has the ability to tolerate delays, depending on how it is built and the tools that help it to operate. Normally, communication delays can range from several microseconds to hundreds of milliseconds [40,75,88,89]. Moreover, according to some other reports [62,86], the normal 150 to 300 milliseconds of telecommunications are considered to be the plans to perform actual transient stability control system, stability index, fault clearance time and delay in response. In this work, a lot of simulation is done with different values of delay. Some systems can withstand a delay of 100 ms, while other systems have a delay of 200 ms. For the power system model, we tested in this process, if the delay is more than 300 ms, then the system presentation is compromised, and the system changes smoothly. Therefore, it can be said or expressed that the extreme allowable delay on this system is 300 ms.

5.1.1. Scheme of Fuzzy Logic Controller

The braking resistors are switched using fuzzy design logic controllers, which are defined in the section below.

Fuzzification

Figure 3 demonstrations the anti-brake (BR) value of the GTCSBR conductor connected through the thyristor to one of the generator bus lines. Brake rotation is performed by the fuzzy logic controller. All total kinetic energy deviation (TKED) is used as input to the fuzzy switch controller. For diagrams requested by the fuzzy logic controller, the time from the TKED of the generator, TKED, and firing angle, $\propto$ was selected as input and output. In this case, the difference is between the total kinetic energy (W_{total}) of the generator in the transient state and that the constant state is defined as the total kinetic energy, $TKED$, i.e., TKED = (W_{total} for the transient state) $-$ (W_{total} for the state stability). The performance of the TKED triangle is shown in Figure 4 where the N, Z, and P variables are negative, zero, and positive. It is important to note that member functionality is the same for each fuzzy controller. A comparison of the performance of a triangular member is used to determine the level of member values and the following [110]:

$$\mu_A(TKED') = \frac{1}{b}\left(b - 2\left[TKED' - a\right]\right) \tag{1}$$

where $\mu_A(TKED')$ is the value of the points of the members, 'b' is the width, 'a' is the sum of the points where the members are 1, and '$TKED'$' is the value of the input of the variables.

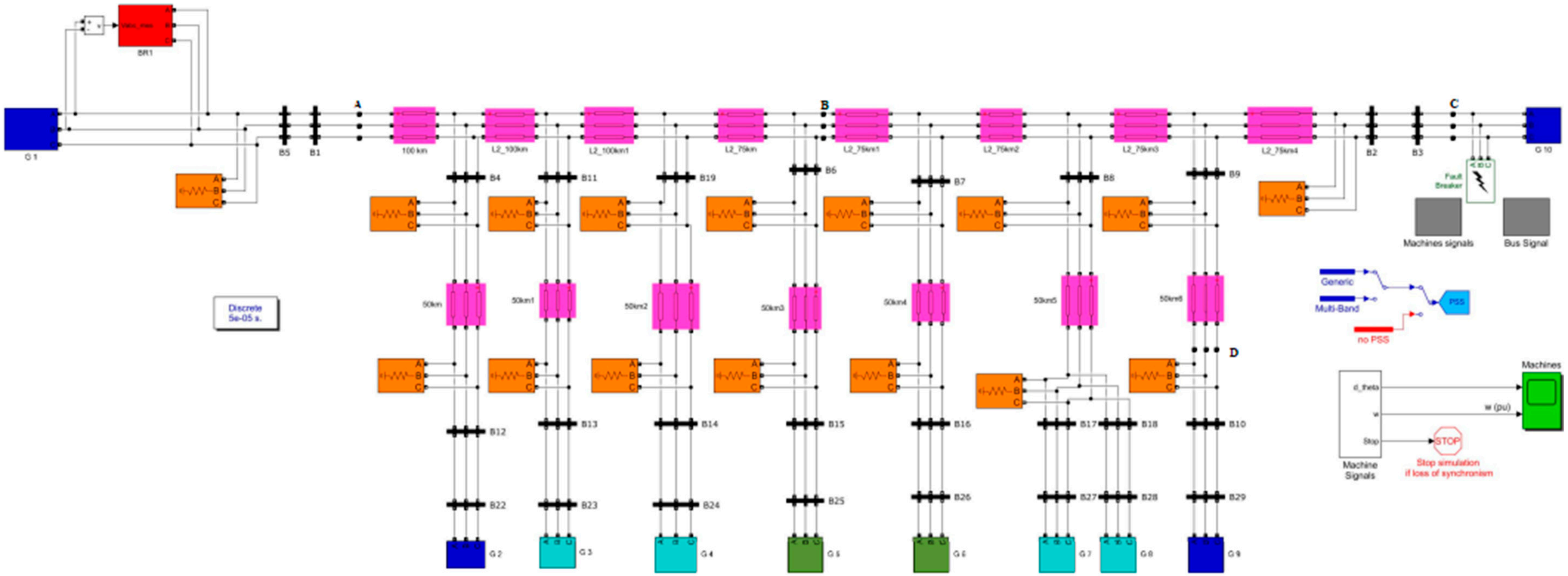

Figure 2. IEEJ WEST 10-machine model.

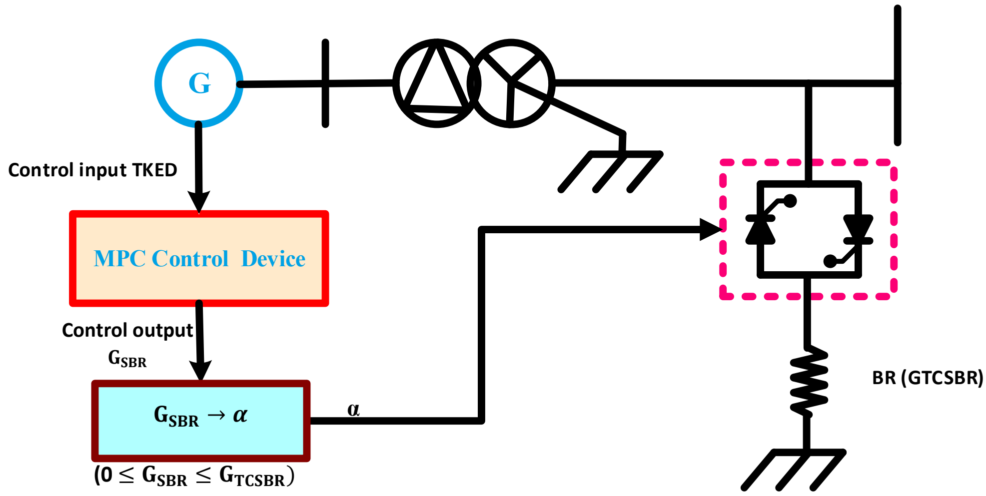

Figure 3. BR with thyristor switching circuit.

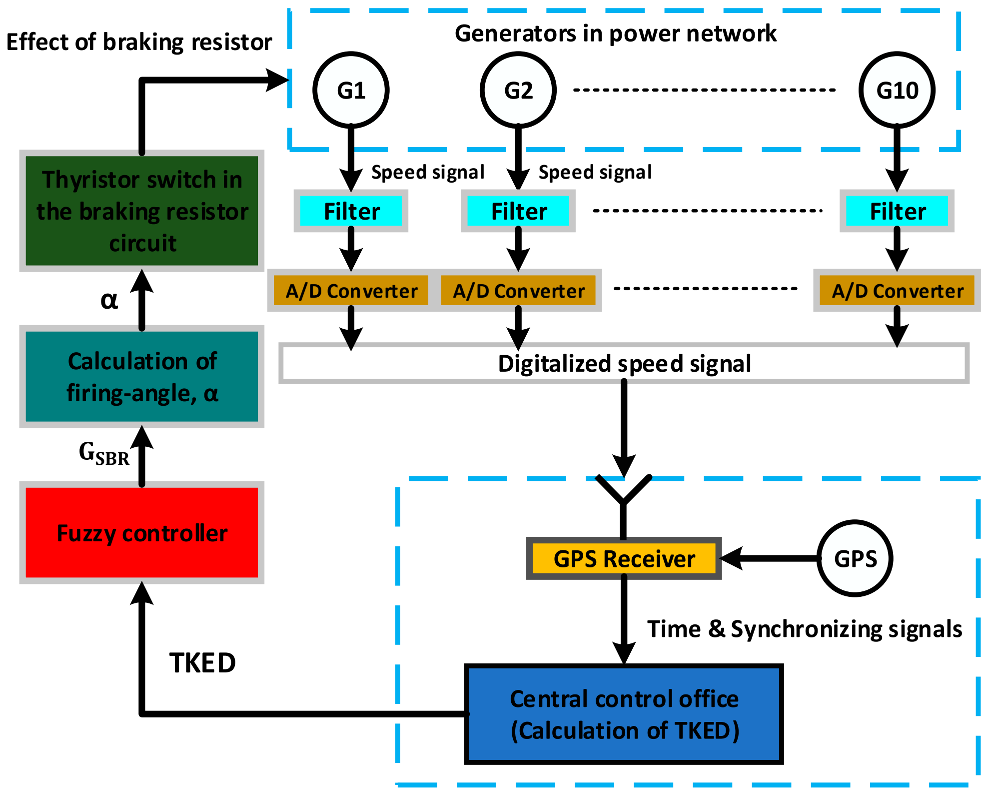

Figure 4. Closed loop control system counting GPS occupation [111].

Fuzzy Rule Table

A unique feature of the fuzzy controller is its simple design, which has only one input and output. The use of inputs and outputs makes fuzzy control more efficient [111]. The planned control approach has only three control rules for each controller as shown in Table 10, where the values of α according to the language changes indicate the fuzzy output of the controller.

Table 10. Fuzzy rule table.

$TKED'$ (pu/s)	α (Firing Angle)
N	Big
Z	Medium
P	Small

Fuzzy Inference

By deciding on fuzzy research, Mamdani's method [110] is used. For Mamdani, a degree of connection, W_i of each fuzzy command is as follows:

$$W_i = \mu_A(TKED') \tag{2}$$

where $\mu_A(TKED')$ is the minimum score for members and i is the rule number.

Fuzzy Inference

The central region is a well-known and easily devalued method that is implemented to determine the output value (i.e., GHF) [112]. This is provided by the following statement:

$$\propto = \frac{\sum W_i C_i}{\sum W_i} \tag{3}$$

where C_i is the price of $\propto$ in the fuzzy instruction table.

One key point to note here is that normally two input elements (error and time derivatives) are used in fuzzy logic design. In this work, the first two input elements (TKED and its derivatives) are used. On the other hand, the presentation of the two input variables was almost the same as the use of the same variable. In addition, the use of two input elements increases the number of fuzzy rules and member activities. For that reason, to make a simple controller, only one input, i.e., time the origin of TKED is used in this work.

An adaptive neuro-fuzzy inference system (ANFIS) logic expands on two-valued Boolean logic by allowing truth values in the continuous interval [0, 1], where 0 is not absolutely true, 1 is absolutely true, and all values in between are degrees of truth. This expansion is best suited for resolving problems involving uncertainty or ambiguity. Because each controller is controlled by only three IF-THEN control rules, the ANFIS method of control is very simple. It should be noted that the control rules were developed through trial and error using system-specific functions. A brake resistor (BR), for example, can produce and use active power at high speeds (P: Positive), but not at low speeds (N: Negative). Furthermore, the brake resistor is not required to use active power consumption while the system is in steady-state (Z: Zero). As a result, the ANFIS rule table is made up entirely of positive (P) elements.

In this work, a lot of imitation has been done cheaply for a short-term analysis based on different values of communication delays, the consequences of this are discussed in more detail in the table below. Figures 5 and 6 show the active power responses without and with fuzzy controlled BR. Communication delays are not considered in this case. It is clear from these results that the system is in good standing when BR is used by fuzzy. Figures 7 and 8 show the heavy load with the fuzzy controlled BR during a delay of between 200 and 300 ms. It appears that the short-term performance in Figure 8 is worse than that in Figure 7. This fact shows that the delay in communication affects the transient stability performance, the amplitudes of G2 and G3 reach and increase as shown in 1 s.

Table 11 displays the (W_c) values for 3 LG in the faults shown at 4 different points from A, B, C and D as shown in Figures 7 and 8 with related to different communication delay values such as 50, 100, 200 and 300 ms intended for use and fuzzy controlled delay minimization technique. The simulation results from that review paper indicate that in order to maintain the stability of the system, it is necessary to have a low-latency communication. The larger communication delay causes slower control actions (fault clearance time) that can cause power system instability and oscillation. As the network delays increase from 50 ms to 300 ms, the rise in the system overshoots and longer settling time is experienced by the control system.

It seems that the BR-controlled fuzzy works fine in the improvement of evolutions, to quiet down erroneously in different places. It is also appreciated selection that the (W_c) values correspond differently, the communication delays vary according to the subjects. Here the truth is that the communication delays are related to the number of fuzzy lines in the BR controller, the change affects the line in the short term. As can be seen in the Table 11, it is clear that fuzzy-controlled BRs are useful in improving short-term stability by correcting different points. As it turns out, communication delays are related to the number of fuzzy controller lines in the BR input controller that change the short-term effect of a grid faults. To understand the effect of communication delays on the integration of components of the power system, we first conducted research when communication delays were zero. And we continue to examine the short-term system when it comes to matching deviation of total kinetic energy (W_c) values as provided by

$$W_c(\mathrm{s}) = \int_0^T \left| \frac{d}{dt} W_{total} \right| dt / system\ base\ power \tag{4}$$

During the process of determining the structure of the system, it becomes known and there is a control over the working time. And T is an imitation time of 0.7 s, while W_{total} is the sum of all kinetic energies, as shown in Equation (4). And due to the desire to reflect on the efficiency of the system downtime it required the use of W_c.

$$W_{total} = \sum_{i=1}^{N} W_i \tag{5}$$

where

$$W_i = \frac{1}{2} J_I {\omega_{mi}}^2 (J) \tag{6}$$

As the system is built to control power generation behavior, W_i shows the kinetic energy (in joules) of the generator, i shows the number of generators, and N indicates the total number of generators.

$$J_i = \frac{H \times MVA\ rating}{5.48 \times 10^{-9} N_s^2} \tag{7}$$

where

$$\omega_{mi} = \frac{2\pi N_R}{60} \tag{8}$$

Moreover, in Equation (4) shows the moment of inertia in Kg·m^2 where N_s^2 are synchronously accelerating at constant rpm and inertia is constant, and, also, the ω_{mi} is rotor the fastest speed in the (mechanical rad/s) and N_R where the rotor speed in (rpm).

Table 11. W_c Values and communication delays.

Fault Point	Communication Delay	Head Value of WC (s)	
		Without BR	**With Fuzzy Controlled BR**
A	50 ms	235.756	33.586
	100 ms		35.276
	200 ms		39.359
	300 ms		43.196

Table 11. *Cont.*

Fault Point	Communication Delay	Head Value of WC (s)	
		Without BR	With Fuzzy Controlled BR
B	50 ms 100 ms 200 ms 300 ms	71.895	30.314 32.896 36.945 37.998
C	50 ms 100 ms 200 ms 300 ms	154.352	40.412 41.834 43.846 44.605
D	50 ms 100 ms 200 ms 300 ms	69.874	34.769 35.934 39.436 39.768

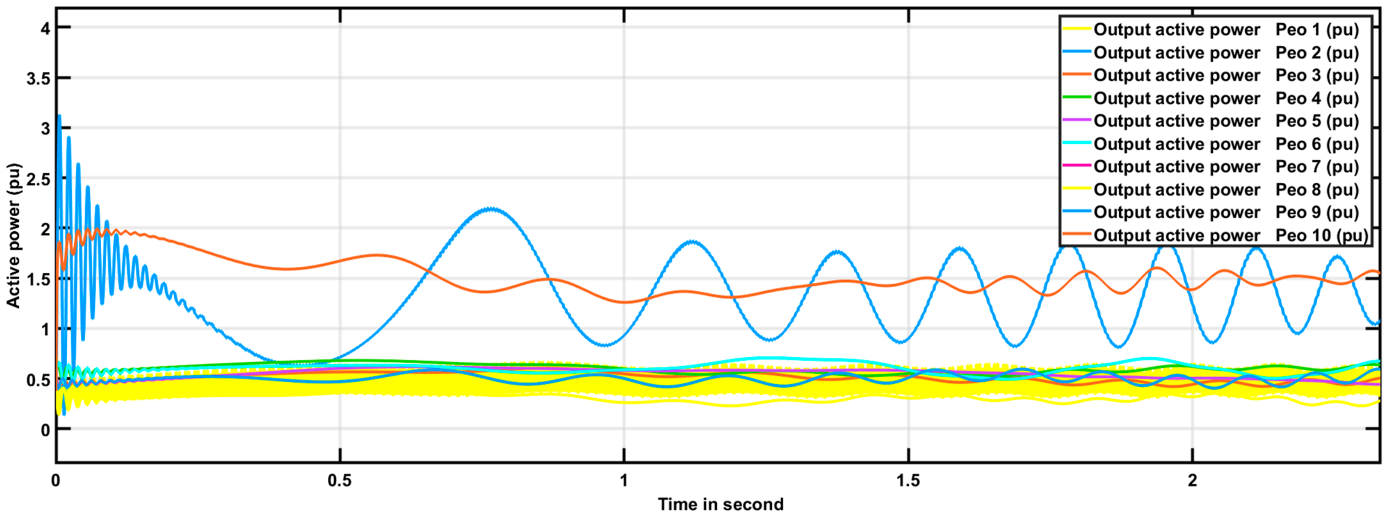

Figure 5. Active power responses without BR and communication delay.

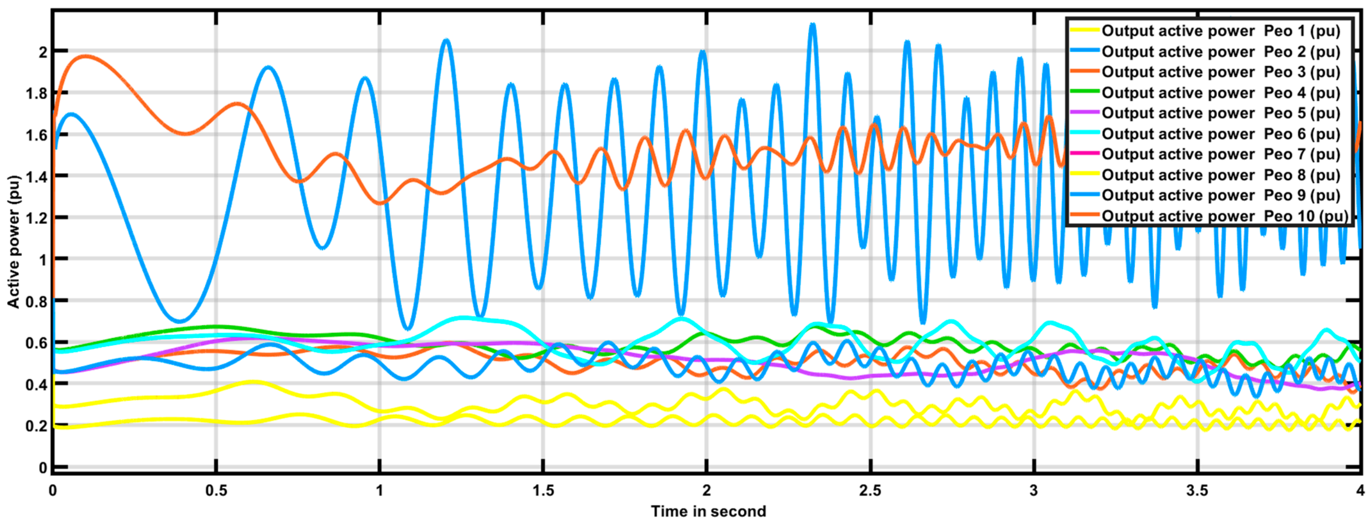

Figure 6. Active power responses with BR and communication delay.

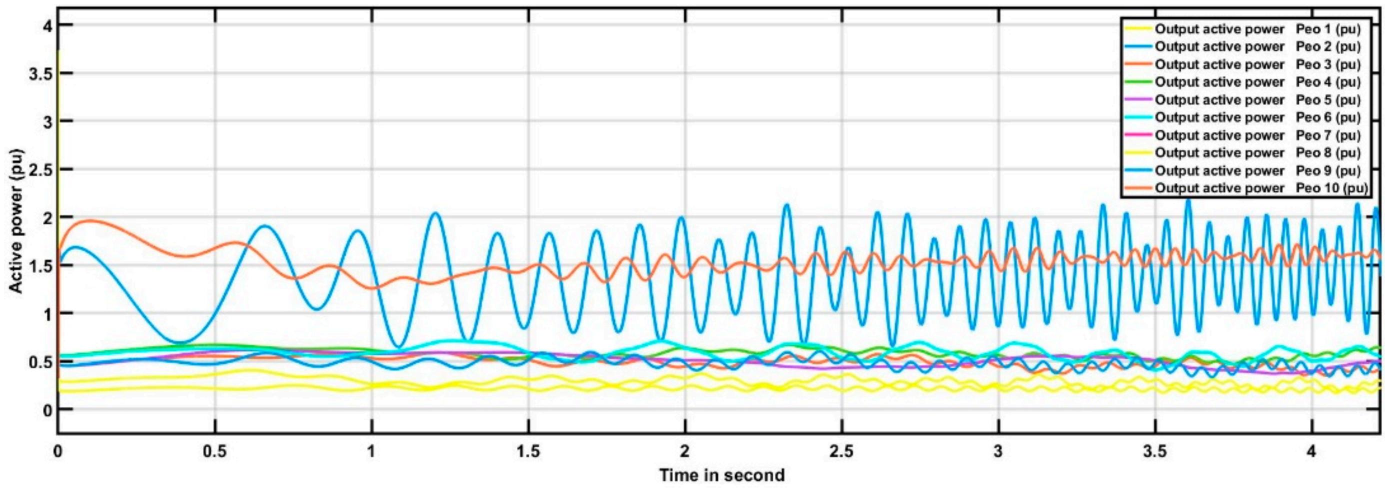

Figure 7. Active power responses with fuzzy controlled BR and communication delay of 20 ms.

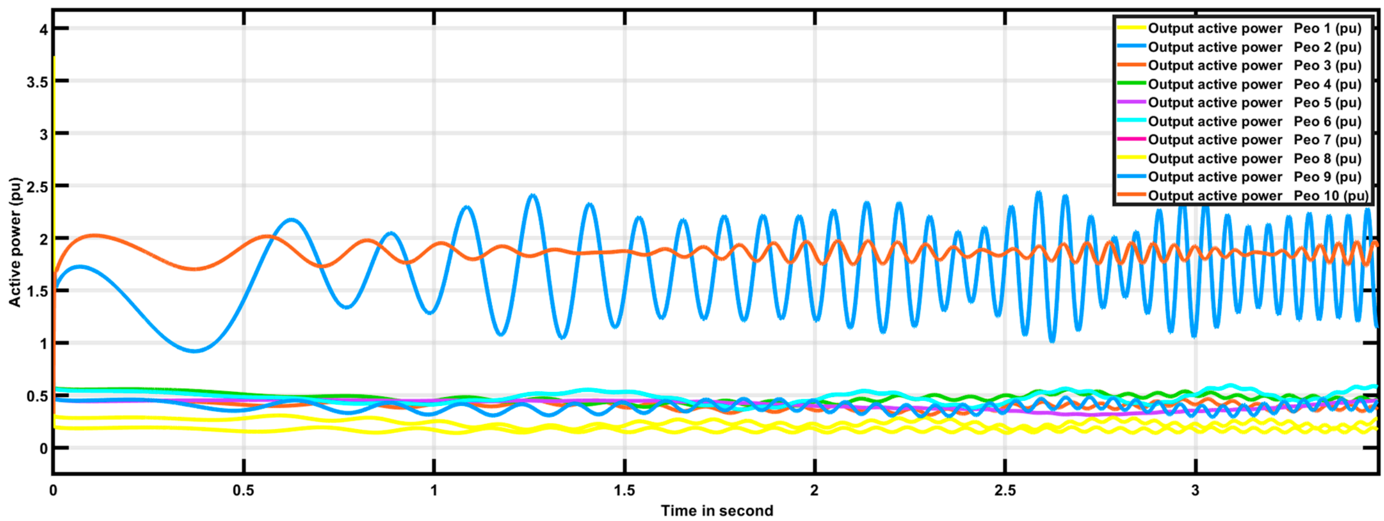

Figure 8. Active power responses with fuzzy controlled BR and communication delay of 300 ms.

The standard IEC 61850 system is advancing in the field of alternative communication, so it is only natural that we would expand this technology in the form of grid security [113]. As shown in Figures 9 and 10, the corrections to points A and C are shown, it is important to understand how to correct or take action in the event of a quick error in order to perform as intended to protect the power system. To be able to limit the fault current before the first current peak, the fault must be detected at least five milliseconds after fault initiation (assuming the apparatus used to clear the fault has zero operating time). In practice, the operating time of a switch used for the current diversion is about 3–5 ms. If a safety margin of 1–3 ms is sufficient to ensure that the fault current is limited before the first current peak, approximately 1 ms is available for fault detection.

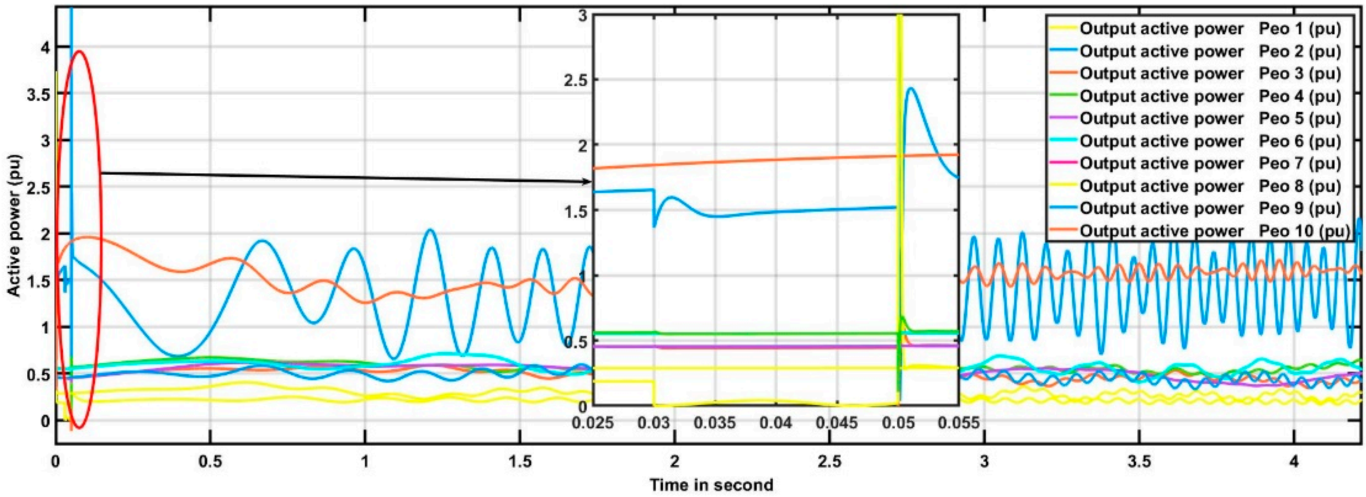

Figure 9. Active power responses for 3 LG fault at point A.

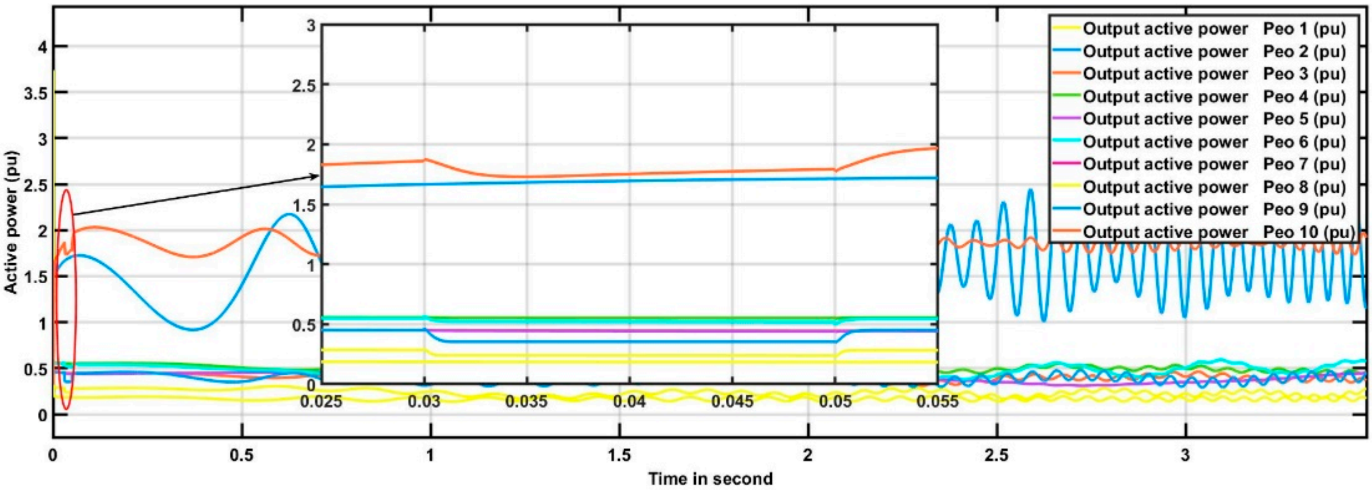

Figure 10. Active power responses for 3 LG fault at point C.

As we have seen above in security management it is important to keep in mind that there are cyber-attacks that go hand in hand with Digital Signals that need to be closely interconnected and go hand in hand when using GPS clocks. However, a number of telecommunications networks may be more vulnerable to service denials and central attacks. Unauthorized attacks can cause false alarms to disrupt the SCADA, resulting in a fire escape system designed by these hackers. The attack can also use a service cut-off or stop the flow of messages and control messages in communication networks. As various studies have shown some of the malware such as Stuxnet and the Botnets that are being used are now showing up in malware. There is also an Advanced Persistent Threat, and Backdoor can severely disrupt communication and connect devices in different parts of the power system. Terrorism will intensify in the smart grid, where communication latency should be low, and instead of delaying the introduction of security measures such as data storage and verification

5.2. General Results Achieved

In the preceding sections, a summary of some results of comparing this delay control method is used for the compensation for delays based on communication to the power control system in the collected works is exposed in Table 7. Comparison between the thirteen verified response strategies described in the table above, considering the importance of numeracy, robustness, numeracy obtained, demonstration of reliance on a model of a wireless system, system security and various other findings of practicality as evidenced by the integrity of the use of the ETDC method and the MFAC method have shown the best results in different latencies that affect the amplitude and frequency of the whole system.

Compared to the stability index we find in Table 11 and others who have prioritized displaying (W_c) values such as [114,115], so our critical indexes you see are good because they are smaller compared to the others mentioned above. Because their stability index (W_c) is so large that their safety is lower than ours we have a small index in various parts that have been considered in the IEEJ WEST 10-machine model. Much of the work has been done in the past to illustrate the impact of communication delays [19–21], on the results obtained based on the impact on the feedback controller. Controllers need to be able to cope with communication delays, and how to reduce the risk of adverse effects should be addressed accordingly. Finding the optimal time to slow down the upper boundaries to determine the stability of the power system, an example of the high response to the results we found that in the 50 ms and 300 ms ranges provide a clear performance leading to a stable stability index in each case. As you can see from the other studies we have done, it has been shown that the stability index we have shown above fuzzy you find gives less results than those who have used other methods as shown in this paper [92,102]. Comparisons with [17,81] have also been made in [65] and it has been shown that their chosen method provides the best system in the event of a communication delay compared to the other two. Thus, the major controller provided in [65] seems to be a choice that should be compared to Lyapunov based indirect method.

As it turns out, a large step was taken to address the effects of delays in the system as a new solution but did not provide a directional approach. The H_∞-based WADC demonstrated good performance in short communication delays but insufficient resilience in high communication delays, which can destabilize the system. Then, with the advent of the Hybrid control system, there is a need to take into account the delays in addressing local and PSS systems and regional and WADC systems. However, the final performance of the low communication delay is not as good as the previous one. In addition, due to the slow communication, the performance of the system and the Hybrid system is still very dramatically. In the wide area environment, time delay occurs in terms of signal transmission and processing especially in the long run. It has been presented that even a short delay can have a detrimental effect on the stable performance of the power system. Therefore, it is very important to study the stability of the power system due to the delay.

As we have seen from the above, there are some solutions that we need to know that each system has to deal with delays in order to function properly. Some systems can withstand a delay of 50 ms while others can work with a delay of up to 300 ms. However, in the case of a power system considered in these tasks, if the delay is more than 500 ms, then the device overall performance deteriorates and the device turns into marginally stable. Therefore, the most allowable put off for the device is 500 ms. As a result, those delays might also additionally differ randomly in a positive range. Therefore, it's far important to estimate the most quantity of time put off referred to as the put off margin that the device should tolerate without turning into unstable. Such know-how at the put off margin (top certain with inside the time put off) could be useful with inside the controller layout for instances in which uncertainty with inside the put off is unavoidable.

Seeking help to ensure security and not forgetting about Sections 2 and 3 and not forgetting the use of Smart Grid Technology (SGT) such as development and measurement, requires media infrastructure to enable two-way communication across all levels of electricity grid-generation, transmission, distribution and consumer mechanisms/parts of the field. These communication requirements include latency, broadband, reliability, and security in order to exchange information and reduce signal delay. The open communication substructures along with Ethernet, the Internet, worldwide interoperability for microwave access (WiMax), and wireless fidelity (WiFi) are gradually being number of applied for smart grid communications. However, delays or loss of information may occur when sent. Therefore, the way out to reducing costs and increasing latency is one of the future directions of microgrid research. And there are some ways we mentioned above that can be used in the Section 7 that can be used to prevent communication delays that affect the operation of the control system, which can reduce power loss and damage to equipment. Another possible concern is that there is a delay in communication and communication due to cyber-attacks that need to be addressed using tracking and response equipment, as well as vehicle analysis.

6. Smart Grids Face Challenges in Terms of Stability and Control

Tests for in-depth analysis of communication delays and loss have been exacerbated by various aspects, including stability evaluation and control of smart grids that have been briefed as detailed below.

Modeling methodologies: Due to the uncertainties introduced by the integration of communication technology and the power system, traditional deterministic modeling strategies used in electricity system analysis are no longer adequate for modeling the smart grid. It is critical to develop new modeling strategies for smart grid staleness analysis and management, such as event-based strategies, hybrid stochastic methods, probabilistic analysis strategies, and so on.

Control methodologies: As discussed in the preceding sections, communication delays networks, renewable energy sources, and security devices such as relays that appear in the stability and control of the smart grid. Deterministic control cannot ensure the overall stability of electricity dynamics. As a result, extensive research on control methods, as well as analytical approach and optimal control gain [50], a random model predictor control, and so on, is required.

Communication construction: since it necessitates the integration of numerous interconnections consisting of generation, transmission, and distribution based on wide-area control, it necessitates large bandwidths for data transmission and data collection. Furthermore, because a smart grid communication structure includes a wide area network (WAN), a neighborhood area network (NAN), and a home area network (HAN), these various network structures require the ability to bring together communications within each subarea and between specific areas.

Stages of simulation: Interaction between the communication network and the power grid is critical for smart grid control and operation. In addition, many important renewable energy sources, such as wind and PV, are linked to the grid via electronic power converters. These changes present two new challenges to network control: broadband pulse size modulation signals, various synchrophasor communication technologies between devices, and a plethora of switching devices. Large efforts should be made to increase simulation systems for intelligent grid research in order to better identify new controls and performance strategies for intelligent grids. Recently, real-time simulation platforms for intelligent grids have been mentioned [116].

7. Concluding Remarks and Future Potentials

This piece of paper shows a review of the analysis that leads to the effect of communication delay by controlling the performance and quality of the electricity grid. Various control methods for analyzing the impacts of network-induced delays on these communication-based strategies are briefed and compared. Strategies that have been thought out and achieved should be shown to be delayed by a continuous or irreversible delay, and that sudden delays are more difficult to solve than permanent delays. To reduce network latency due to delays, it has to imitate appropriate compensation plans that are designed to reduce or eliminate adverse effects on the functioning of the system. As we saw above in Table 8 and Section 6, it can be seen that the method has different capabilities in reducing delay, while all the above methods were appropriate for the linear system, only the stress-based, robust and incident-based methods can work on non-linear systems. Compensation plans, such as the revised ETDC & MFAC show the progress of research in reducing the various delays. Based on the problems described in Section 6 there is a quick way to reduce the various sudden delays that should be taken into account in the following areas:

- Communication network is a network of choice based on latency.
- Network control system issues are limited to online delays.
- Delay is considered to be between the sensor and the controller, between the controller and the actuator, and the combination of both delays;
- Imitation is done by delaying suddenness and suddenness.

In addition, it'll be exciting to reveal the effectiveness of the proposed techniques in case of a large electricity network such as no one else has ever done that leading up to the Rwanda National Grid project, in which the total harmonic distortion (THD) values may be large than 5%.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

SDC	Supplementary Damping Controller
DD-WADC	Delay-Dependent-Wide Area Damping Control
DOF-WADC	Dynamic Output Feedback–Wide Area Damping Control
BA	Bat Algorithm
BESS	Battery Energy Storage Systems
DOFC	Dynamic Output Feedback Controller
POD	Oscillation Damping
MPM	Modified Predictor Method
POD	Oscillation Damping

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