Impacts of Packet Losses and Delay in a Networked Control Hydroelectric Power Plants

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Abstract*:-* Nowadays, real-time control systems located throughout communication network are increasingly being used in the sectors of mobile robotics, telecommunication and more generally in the control of industrial processes for obvious flexibility reasons, compactness and reduction of the cost of installation etc. As the network is shared by several loops of control and other applications, the consequence is that the traffic of communication is not easily controllable, which can lead to packet losses and generates random delay. The objective of this Paper is to show the impact of degradations induced by the communication network applied to a frequency controlled hydroelectric power plant so that they are taken into account in the design of the laws of control in order to guarantee the performances of the system of control/order according to criteria of stability and performance.

Keywords: Communication network, packet losses, delays, hydroelectric power plant, frequency.

1. INTRODUCTION

Network control systems are current themes of research; the essential points of the rise of the Network control systems scientific community are due to technological progress which render more powerful the communication and treatment resources. However, the increase in technological performances of networks leads to decompartmentalize the network while entrusting to it the mission of transferring communications related to the industrial process and of facilitating the integration of new functions by amalgamating the corporate networks. As the network is separated into several control loops and other applications, the consequence is that the traffic of communication is not easily controllable, which can lead to data losses [1-3], random transmission times [4,5] capable of affecting information (command and measurement) to be transmitted on a process.

It is thus necessary to model and evaluate the characteristics of the network in terms of transmission times and packet losses. In existing work, the characterization of transmission times is often based on unverified assumptions, such as the transmission time distributed according to a Markovian process [6,7], the packet loss according to Bernoulli's law [3], a Markov chain describing the process of packet losses was considered in [8-10]. When the process of losses of packages is modelled by a process i.e. with a given probability of packet losses, a condition necessary and sufficient for stability called "mean square stability" is given in [11]. Where as in reality, the transmission times strongly depends on the network saturation at the given time t, on the protocol and the policy of the resource allocation. It is thus necessary to study the system with a model of finer network model reflecting its true behavior accurately. In this article, we have developed models for the disturbances close to reality, reliable and robust describing the process of packet losses and transmission times with a discrete system of modeling and simulation tool (MATLAB/Simulink/State flow). In this context, we applied in simulation these various classes of disturbances to a real system (hydroelectric power plant of Songloulou) [12] in order to highlight the impact of these degradations induced by the digital communication network on the system.

The contents of this article are structured as follows: We presented in section 1 a review on the system on which we worked; then we presented in the section 2 models of the two classes of disturbances. The results obtained from simulation are given and analyzed in section3. Then comes a conclusion where the prospects opened by this work are evoked.

2. MODELING

1) 2.1 Modeling of the hydroelectric power plants

The hydroelectric power plant of Songloulou has the following characteristics [12]: Francis Turbine (P=49.5MW, D=4.55m), synchronous generator (S=57MVA, cosφ=0.85, U=10.3kV, D=9.20m, J=8800t/m^2), Ethernet network, SIEMENS PLC. This power plant has a line of entirely automated and supervised production.

Figure 1 shows the diagram of the hydroelectric power plant, the hydraulic control circuit, the signals of the device of winnowing and the communication network devices. This power plant functions by exploiting the energy provided by the tides. The management of the signals at the level of the winnowing device where the regulator is associated are presented at Figure 1. The role of the pilot servo valve is to transform an electrical current delivered by the programmable logic controller

(PLC) into a proportionate and exact displacement of a hydraulic distributor, supplies a servo-motor controlling the blades of water conveyance device of the turbine; output power available at the alternator makes it possible to feed an electric charge.

The process is carried out by association of 4 modules: the turbine, the alternator, the servo-motor-servo valve unit, power channels. The model of the hydroelectric power plant including the speed system of regulation system is represented on Figure 2. We find the different transfer function as follow:

The transfer function of the turbine [12]:

$$G_T(s) = \frac{0.663}{1+42.55s} \quad (1)$$

The model of the servo valve is given by [1]:

$$G_s(s) = \frac{20}{1+0.645s+0.00645s^2} \quad (2)$$

The relationship between winnowing (v) and the water flow rate (d) is given by [12]:

$$d = 1.7967v + 0.9874 \quad (3)$$

The Simulink/Matlab model of the power chain is obtained from the equations 7 and 8.

$$Q = 16 + 90\frac{P}{H_b} \quad (4)$$

$$P = \frac{1}{90}(Q-16)H_b \quad (5)$$

Where Q is the turbine water flow rate in m^3/s , P_m is the power available at the end of the rotor shaft in Mw , $H_b$is height of waterfall in m, P_r represents the power of the load in Watts, T_r the resistant torque due to the load in N.m, P_m the active power produced in Watts, T_m the motor torque in Nm , ω_{mes} speed measured at the sheft in rad/s and $d\omega$ the disturbance.

The frequency modeling and regulation was carried out in [12]. Our system uses an RST controller with the following characteristics:

$$R(z^{-1}) = 3.0008 - .2354z^{-1} + 0.5157z^{-2} \quad (6)$$

$$S(z^{-1}) = 1 - 0.5689z^{-1} - .4311z^{-2} \quad (7)$$

$$T(z^{-1}) = 0.28095 \quad (8)$$

From the transfer functions (equations (1), (2), (3), (4) and (5), (6),7), (8)), we obtained in Figure 2, the Matlab/Simulink model of the power plant [12].

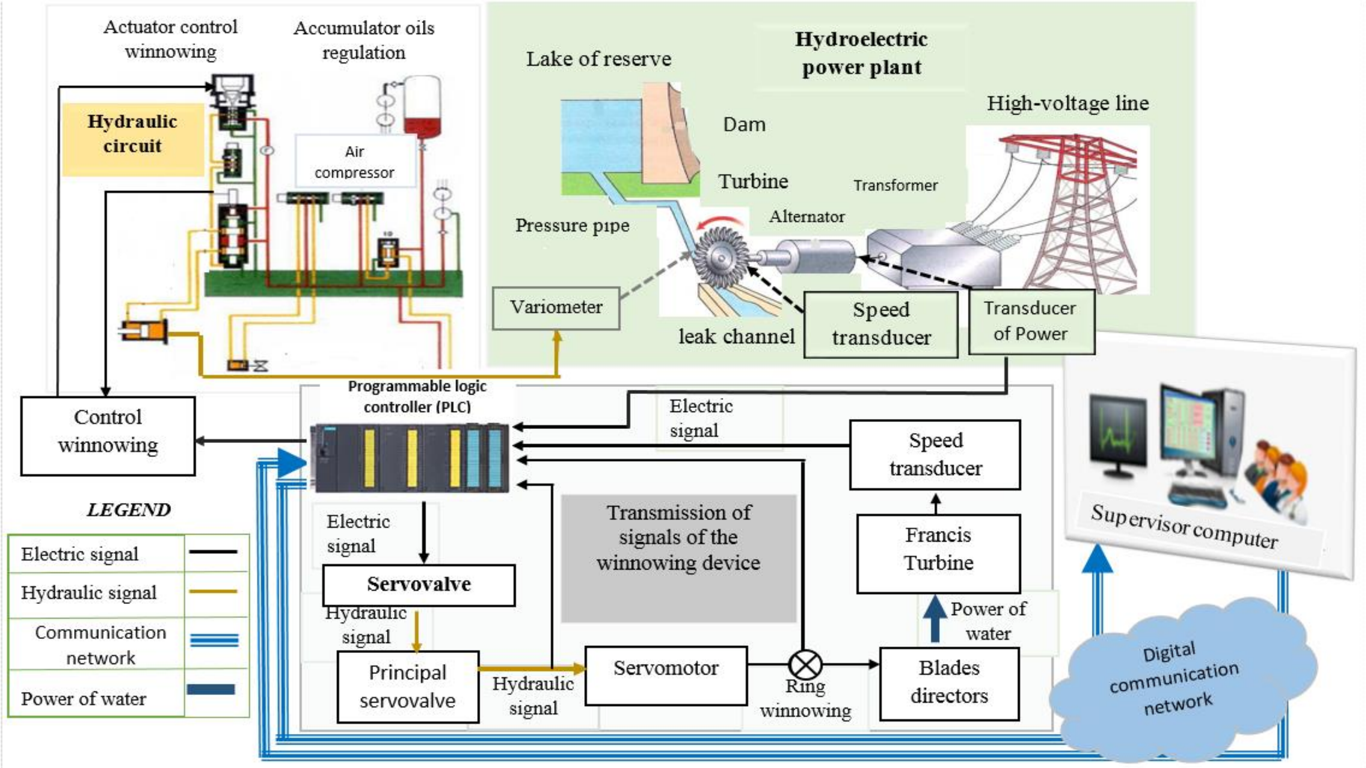


Figure 1: Schematic diagram of an hydroelectric power plant and the communication network.

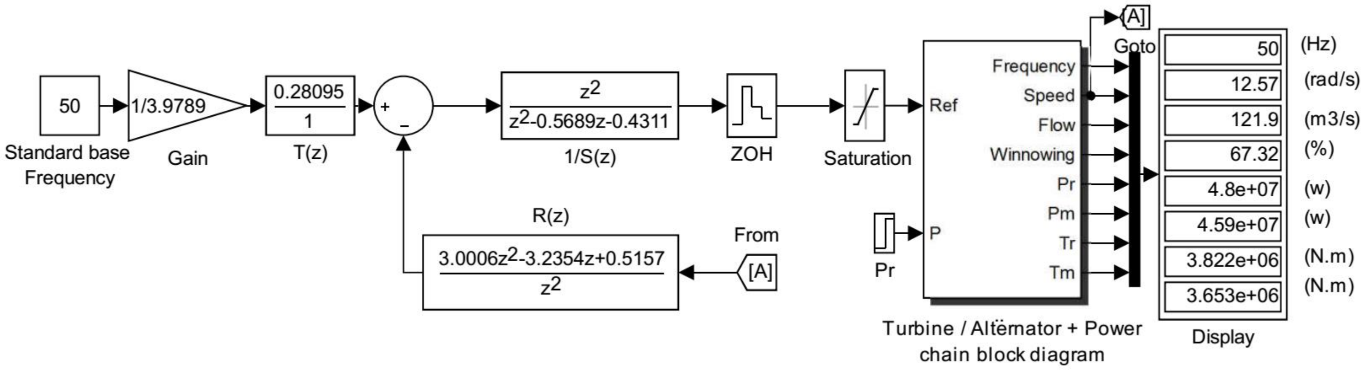


Figure 2. Model of the hydroelectric power plant [12].

2) 2.2 Modeling of the packet losses on the network

The use of a Bernoulli's in two independent variables α and β provides a better modeling of the behavior of these degradations (Figure 1). According to [2,4], we define $\tilde{y}_k$ the output of the system (with internal noise) and y_k the data used with a probability α. In situations where the data is not available, we will use the preceding data y_{k-1} with the probability 1-α. We proceed in a similar way for the entry u_k with the probability β. The following equations describe this phenomenon:

$$y_k = \alpha\tilde{y}_k + (1-\alpha)y_{k-1} \qquad (9)$$

$$\tilde{u}_k = \beta u_k + (1-\beta)u_{k-1} \qquad (10)$$

The representation of packet loss on a system connected in a network is presented on Figure 3 [4].

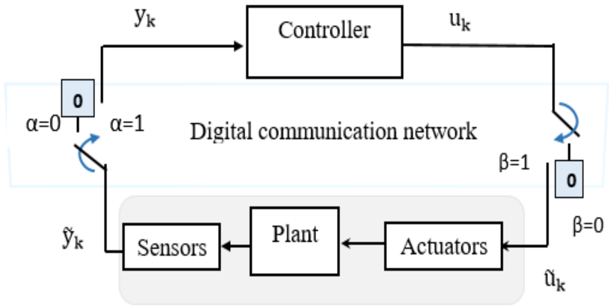


Figure 3. Representation of packet losses on networked control system.

Figure 4 presents the Simulink/State flow model of packet losses at the level of measurement. This model is obtained by implementation of the equation (9) the block " Chart " contains the diagram described it makes it possible to generate Boolean values (α) making it possible to activate the disturbance with each falling limb of the pulse generator. Figure 5 presents the model of the packet losses on the control. In this structure when the order u_k is not available, we will use the preceding order u_{k-1} with probability 1-β. This model is obtained by implementation of the equation (10) ; the block " Chart " makes it possible to generate the random variable β .

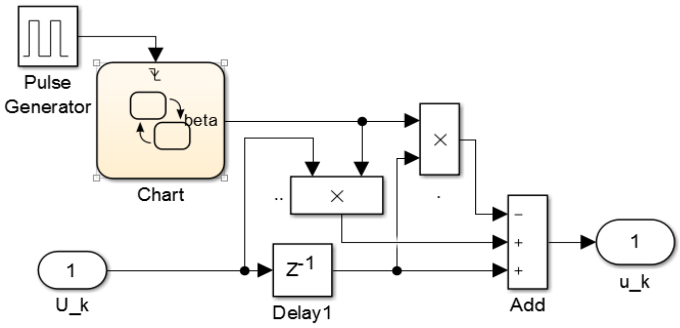


Figure 4. Model of packet loss on the control.

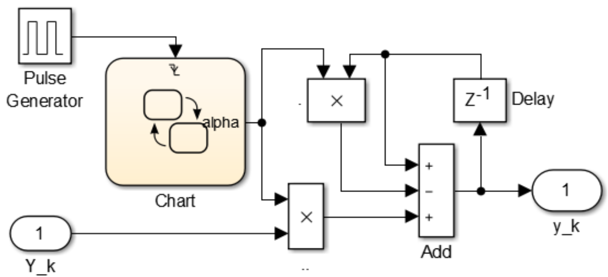


Figure 5. Model of packet loss to the measure.

2.3. Modeling of the delay of transmission on the network

The introduction of a communication network into a control loop of control can induce random transmission times of information (command and measurements) to transmit on a process [4]. Several works [13-18] show that it is possible to model the appearance of the delays by using Markov chains. This chain can model several states where the first does not represent a potential degradation. The presence of a degradation is characterized by a change of state. The conditions of transition of this chain are λ_{ij} and π_{rs} defined by the equations (11) and (12).

$$\lambda_{ij} = P(\tau_{k+1} = j|\tau_k = i) \qquad (11)$$

$$\pi_{rs} = P(d_{k+1} = s|d_k = r) \qquad (12)$$

Where τ_k and d_k are respectively random transmission times on measurement and the control; their general probability of transition matrices are defined by $\Lambda = [\lambda_{ij}]$ and $\Pi = [\pi_{rs}]$ respectively.

With $\lambda_{ij}, \pi_{rs} \geq 0$ and $\sum_{j=1}^{r} \lambda_{ij} = 1, \sum_{s=0}^{d} \pi_{rs} = 1 \; \forall i, j \in \{0,1,\cdots,\tau\}$ and $, r, s \in \{0,1,\cdots,d\}$.

The representation of delays on a system connected in network is illustrated on Figure 6.

It is supposed that random deadlines induce in the system are: $d_k \in \{0,1,2\}$ *and* $\tau_k \in \{0,1,2,3\}$; their probability of transition matrices are given respectively by:

$$\Lambda = \begin{bmatrix} 0.6 & 0.4 & 0 \\ 0.5 & 0.4 & 0.1 \\ 0.5 & 0.4 & 0.1 \end{bmatrix} \qquad (13)$$

and

$$\Pi = \begin{bmatrix} 0.55 & 0.45 & 0 & 0 \\ 0.59 & 0.11 & 0.3 & 0 \\ 0 & 0.52 & 0.38 & 0.1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \qquad (14)$$

We builded a state machine of this chain. The passage from one state to another is done by a transition which is materialized by an oriented connection between a source state and a peak state and will be done with the occurrence of two external event (generating of random variable (rand) and of the pulse generator). The probabilities of transition remain constant with time; Figure 7 describes this chains.

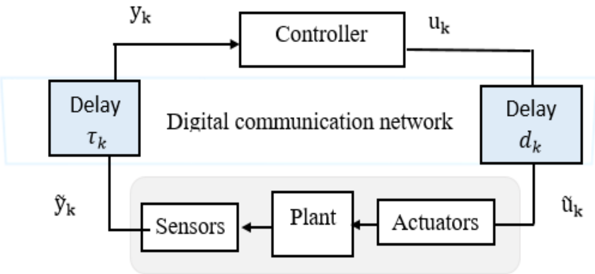
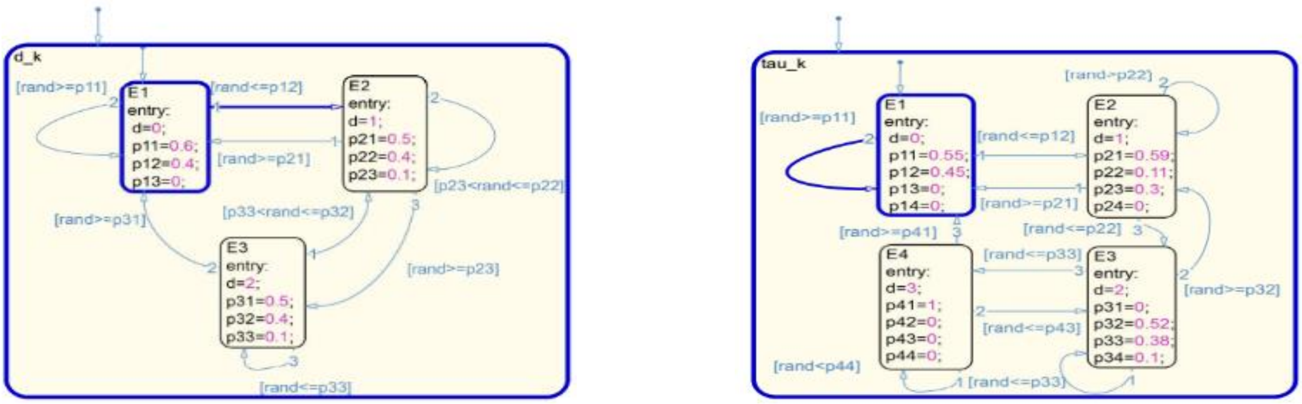


Figure 6. Representation of random delay on networked control system [4].



(a) **(b)**

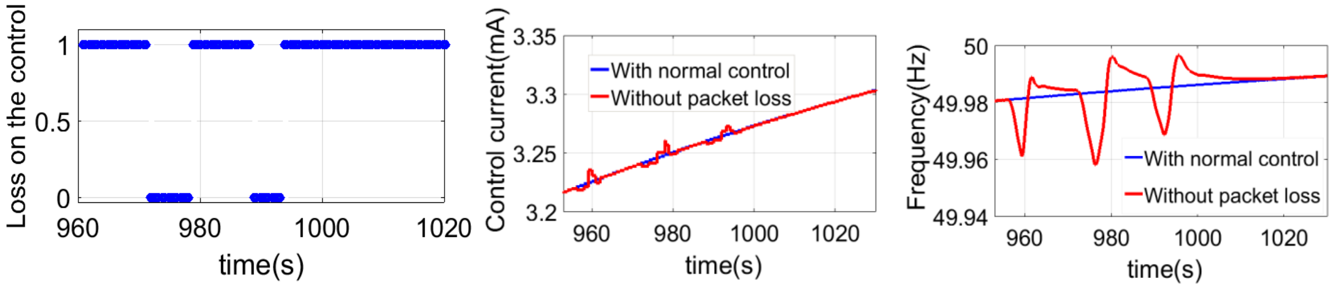
Figure 7. Stateflow chart for the markov chain of dk (a) and Stateflow chart of the markov chain of τ_k (b).

3. RESULTS AND DISCUSSION

3.1. Simulation of the system subjected to packet losses

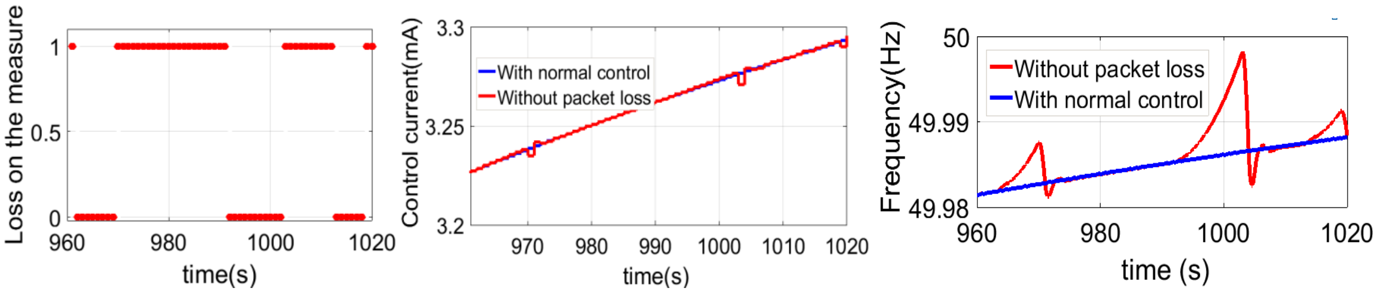
We will show the influence of packet losses applied at the level of the order and at the level of measurement by the programmable logic controller(PLC). Figures 14, 15 and 16 respectively present the models of the power plant with insertion of the block of packet losses at the level of the PLC control, at the level of the PLC measurement and at the level of the PLC control or measurement. These models make it possible to simulate the theoretical behavior of the system vis-a-vis of these degradations.

3.1.1. Simulation of the system subjected to packet losses on the control



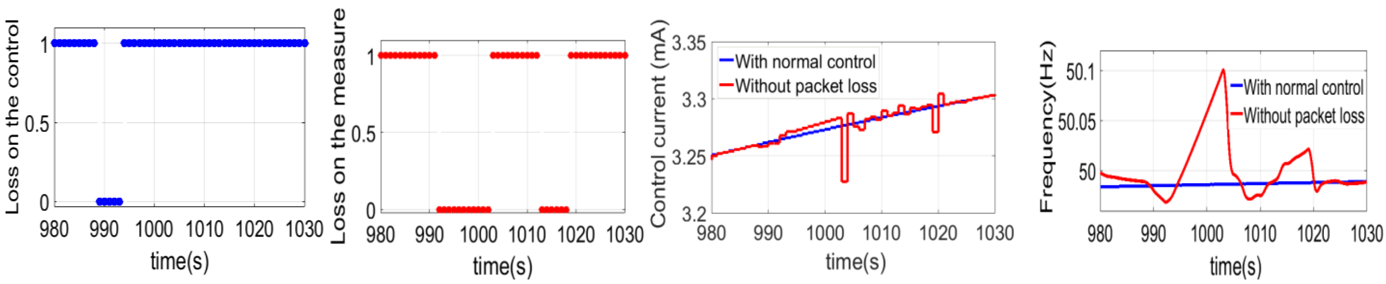
(a) (b) (c)

Figure 8. Packet losses on the control (a), effect packet losses on the current control (b), effect packet losses on the frequency(d).



(a) (b) (c)

Figure 9. Packet losses on the measure (a), effect packet losses on the current control (b), effect packet losses on the frequency(d).



(a) (b) (c) (d)

Figure 10. Packet losses on the control (a), packet losses to the measure (b), effect packet losses on the current control (c), effect packet losses on the frequency (d).

Table 1. Time of appearances of the disturbances

Loss on the control	Loss on the measure	Loss on the control or on the measure
957s to 959s; 962s to 969 962s to 969	*972s to 978s;* 992s to 102s 992s to 102s	*957s to 959s* , 962s to 969 ; 962s to 969, *972s to 978s;* 992s to 102s, 992s to 102s

The results comprise a packet loses on the control of the PLC at the following times (Table1) (Figure8a). Figure 8b presents the compared growth of the current of standard control (blue) and with packet loss (red); we discover that if a packet loss appears the preceding control is maintained which incites a drift of the frequency then controlled (Figure 8c).

3.1.2. Simulation of the system subjected to packet losses to the measure

Figures 9a, 9b and 9c show the results of simulation concerning a loss on the measurement at the following times(Table1). We noticed the appearance of steps on the control (control disturbed) (Figure 9b) which cause drifts on the frequency of the system to be controlled (Figure 9c).

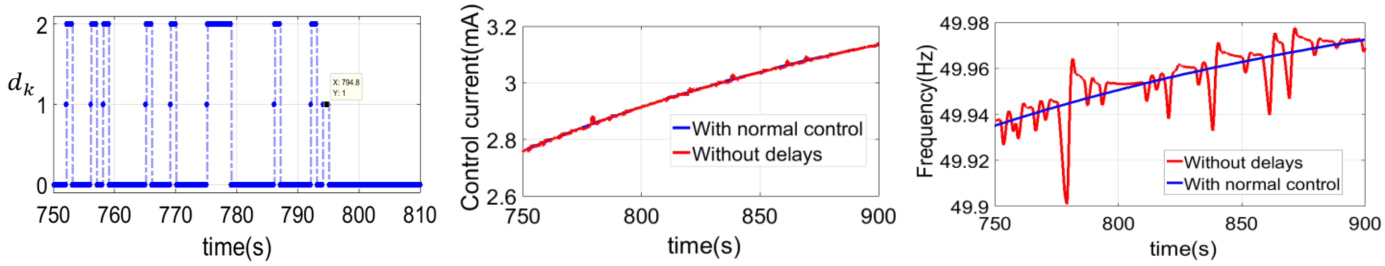
3.1.3. Simulation of the system subjected to packet losses to control or to measure

The appearance of packet losses remains identical to the two preceding simulations. We noticed that a succession of packet loss to the measure followed by of packet losses on the control induces a relatively significant increase on the frequency (Figure10d); this difference is corrected by the closed loop. We also noticed that the control does not react after a packet loss, due to the adjustment of controller RST and the dynamics of the system.

3.2. Simulation of system subjected to delays

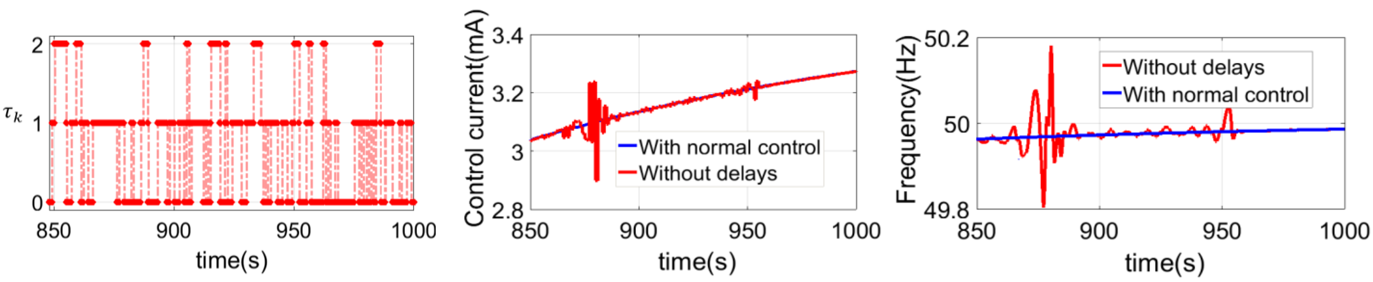
3.2.1. Simulation of the system subjected to delays on the control

In a similar manner to the preceding section, we showed the influence of the delays applied to the control and the measurement of the PLC. Figures 17, 18 and 19 respectively present the models of the power station with insertion of the block of delays on control of the programmable logic controller (PLC), on the measurement of the PLC and on the control or the measurement of the PLC. These models make it possible to simulate the theoretical behavior of the system vis-a-vis of these degradations.



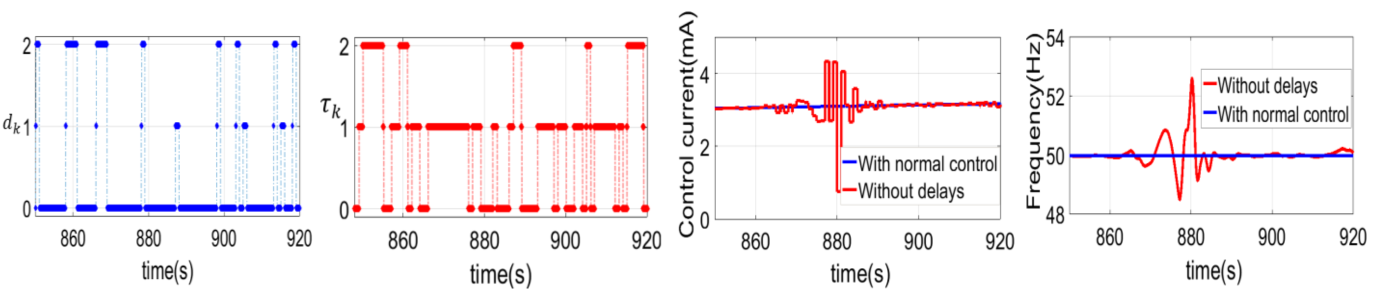
(a) **(b)** **(c)**

Figure 11. Delays on the control (a) , effect of delays on the current control (b) and effect of delays on the frequency (c).



(a) **(b)** **(c)**

Figure 12. Delays on the measure (a), Effect of delays on the current control (b) and Effect of delays on the frequency (c).



(a) **(b)** **(c)** **(d)**

Figure 13. Delays on the measure(a), delays on the measure (b), effect of delays on the current control(c), effect of delays on the frequency(d).

Table 2. Time of appearances of the disturbances

Delay on the control	Delay on the measure	*Delay on the control or on the measure*
752s ; 756s ;759s 775s to 779s ; 778s to 792s ;794s	*859s to 861s; 862s to 864s ;849s; 850s; 879s; 882s*	*849s ; 849s* to *850s ; 858s to 861s ; 857s to 859s ;858s to 861s ;859s to 861s ; 866 to 869s ;862s to 864s; 878s ; 866s to 876s ; 887s ;877s* to *879s ; 898s; 882s ; 903s ;887s* to *889s ; 905s ;893s* to *897s ;913s ;918s ;902s to; 904s ;905s ; 907s to 912s*

Figure 11a shows delays at the following times (table2). These delays on control the PLC cause a slight deviation on the frequency. It is observed that during the reappearance of the delayed packet, the priority will be given to that delayed packet instead of the one envisaged at the given moment. This explains the impact of the delays at the instants 775s to 779s on the evolution of the frequency (Figure 11c).

3.2.2. Simulation of the system subjected to delays on the measure

The results of simulation presented on Figure 12 comprise the appearance of delays at the instants (Table2). We noticed that our control is strongly disturbed (red) with respect to it is the behavior (blue) (Figure 12b) which causes derivations on the frequency (Figure 12c).

We also notice that the reappearance of the delayed packet at the instants (866s to 876s) compels a prolonged oscillation on the frequency.

3.3.3. Simulation of the system subjected to delays on the control or to the measure

The simulation results of with in the framework of delays on the control or to the measure both on the control and on the measure are presented in Figures 13a, 13b, 13c and 13d, we notice that the appearance of delays on the control at the instants (Table2), (Figure *13a*) and to the measure at the times (Table2), (Figure 13b) very strongly impact the output of our system. One observes a very significant oscillation on the frequency when the delays follow one another (Figure 13d).

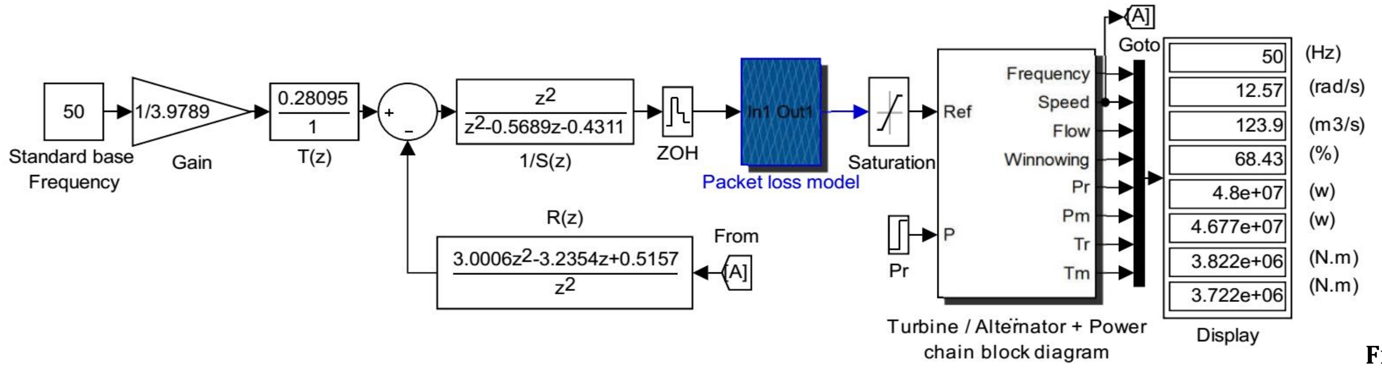


Figure 14. Model of the power plant with insertion of the block of packet losses on the control of the PLC

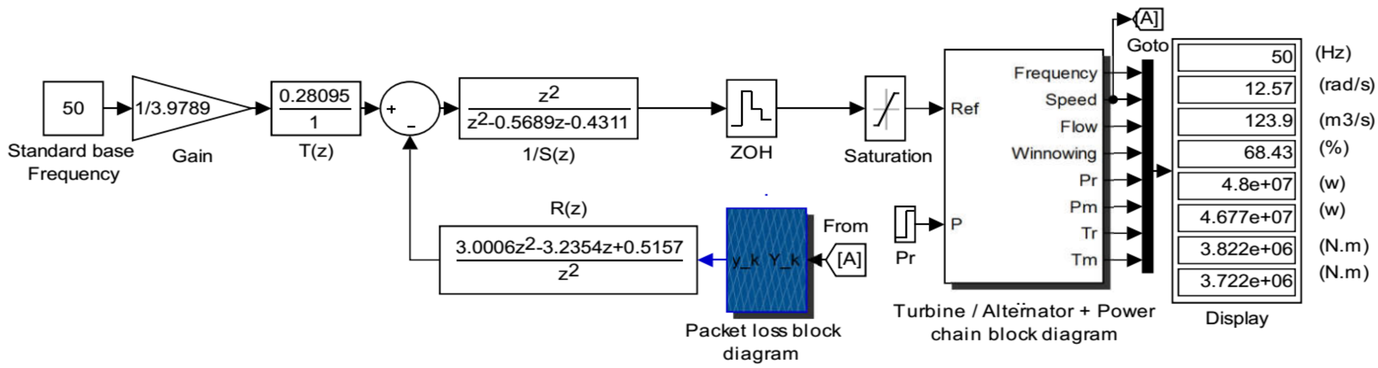


Figure 15. Model of the power plant with insertion of the block of packet losses on the measurement of PLC.

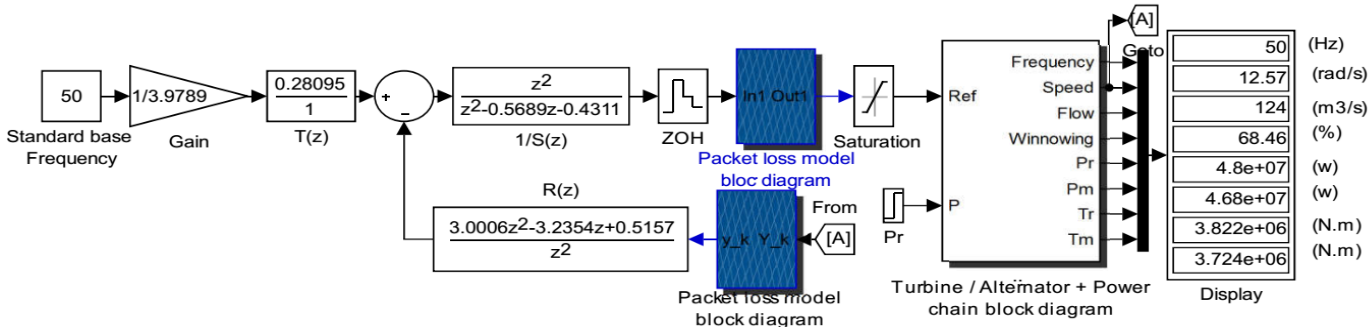


Figure 16. Model of the power plant with insertion of the blocks of packet losses on the control and the measurement of the PLC.

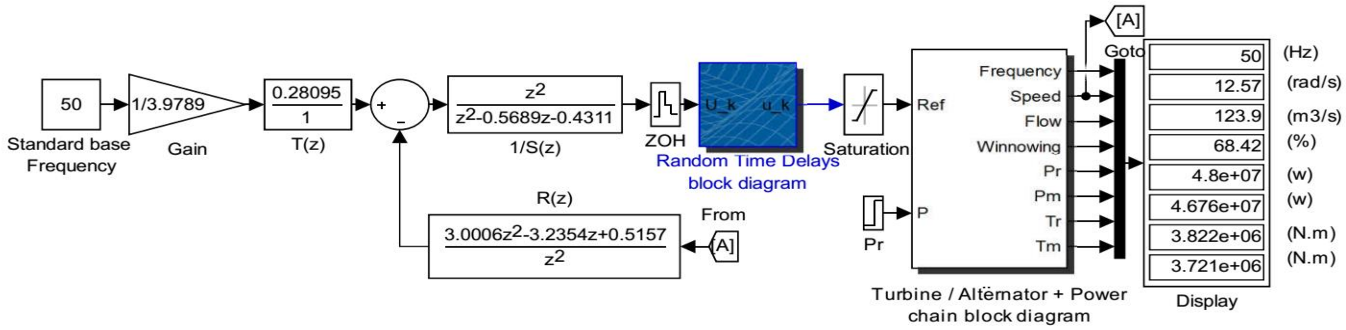


Figure 17. Model of the power plant with insertion of the block of delays on the control of PLC.

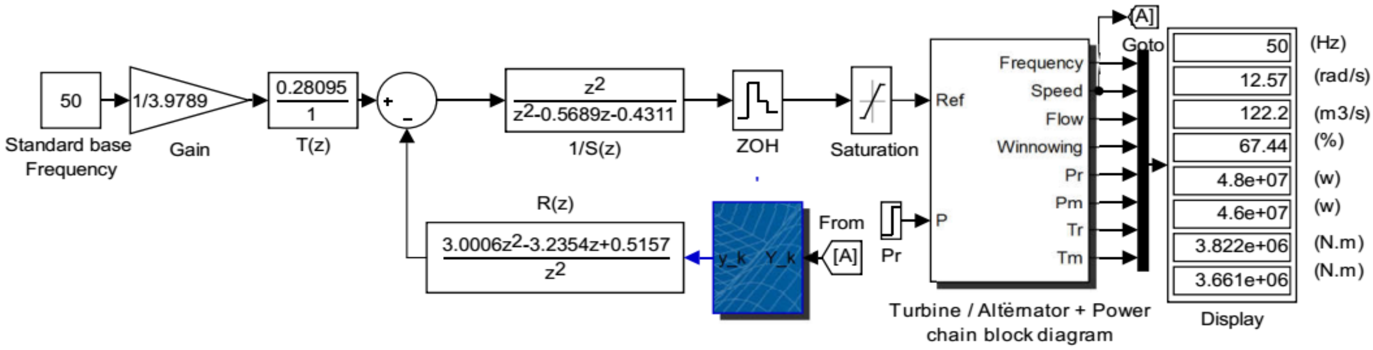


Figure 18. Model of the power plant with insertion of the block of delays on the measurement of the PLC.

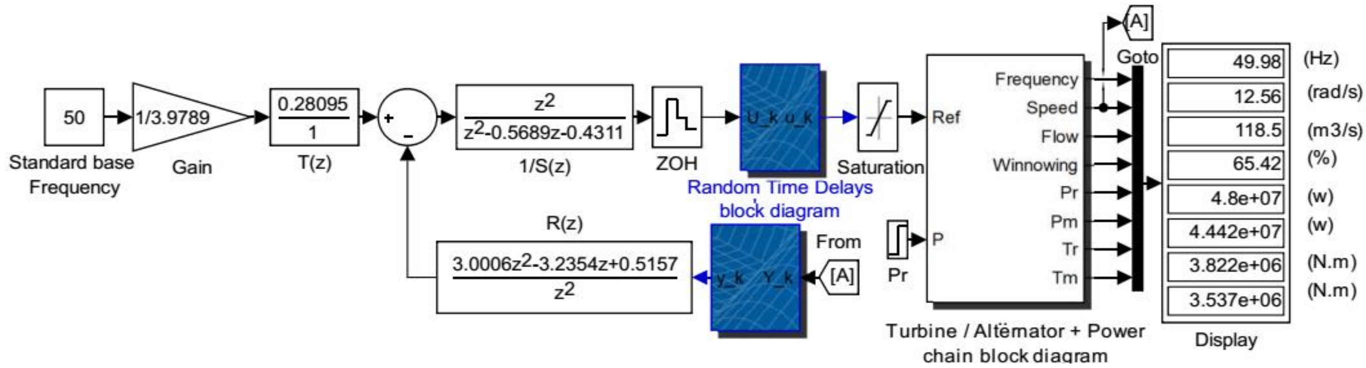


Figure 19. Model of the power plant with insertion of the blocks of delays on the control and the measurement of the PLC.

4. CONCLUSION

In this article, we proposed finer models reflecting the real behavior of packet losses and delays of transmission induced on a networked control system. The various results obtained from the simulation of the various classes of defects applied to the hydroelectric power plant show the impacts of these degradations on the frequency and thus on the regulation of the system. The results so obtained, show that it is important to be able to detect all malfunctioning as regards digital communication network. We wish to develop a tool in the future for diagnosis so detecting the possible aberrations of networked control systems and to check the integrity of the data of communications.

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