Mitigating Communication Delay Impact on Microgrid Stability Using a Compensator Based on Smith Predictor

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***Abstract*— In this study, a control approach based on the model predictive control and Smith Predictor is proposed to compensate the effect of communication delay, and keep the stability of the Microgrid (MG) system. A cyber-physical model for the MG system is introduced to define and test the control and communication functions. The MG system consists of two distributed natural gas generators, an energy storage device, a PV system and a wind turbine with constant power. The Smith Predictor based delay compensator approach is applied to the defined MG based system. In addition, the impact of communication delay on MG is simulated and the behavior of the system with and without compensator is compared. The obtained simulation results show that the proposed approach can significantly decrease the impact of communication latency on frequency deviation and the response of the MG system.**

Keywords— Communication, Compensator, Cyber-Physical Model, Delay, Microgrid, Smith Predictor.

I. Introduction

The Load Frequency Control (LFC) has a significant role to make a balance between the load demand and the generation in each power system as well as in a Microgrid (MG). The main objective of the LFC is to keep frequency in acceptable range with low fluctuation for any level of the load. The communication platform is one of the main part of the MG system in order to send data from the load side to the control side. Based on the communication system, different types of delay will be introduced. On the other hand, communication delays are a big concern for changing the behavior of the system. Therefore, these delays create new challenges about the dynamic response of the MG [1], [2], [3] and using the control architecture.

Two main MG control architectures such as the centralized and the decentralized control methods are proposed and applied. The centralized controller has different control layers called as primary control, secondary control layers. Each component should send their data to the secondary control layer. This increases the communication traffic. Increasing number of component in the MG also increases the size of the data that should be sent to the secondary layer [4]. This leads an increase in communication delay. Besides, the centralized control architecture suffers from single point of failures, and this decreases the reliability of the system [4].

In decentralized control architecture, both the primary and the secondary controller are in the same layer, and each component has its own controller. Therefore, components do not need to send their data to the upper layer. This decreases the amount of the transferred data [5]. Since every component has their own controller, the single point of failure is removed. Thus, the decentralized control architecture improves the reliability of the MG control system.

The outcome of communication delays in power systems encompasses destabilizing the system, decreasing the performance of controller and increasing the magnitude of frequency deviation [1]. The amount of communication delays mainly depends on control architecture, the physical communication layers and transmission protocols. Therefore, it is essential to design a controller to help the system work in the presence of delay without becoming unstable.

MG components may have different dynamics. Therefore, the impact of the communication delay may be different for each component [3], [6]. For instance, the synchronous generators have higher time constant, and this provides some level of delay immunity. The components of

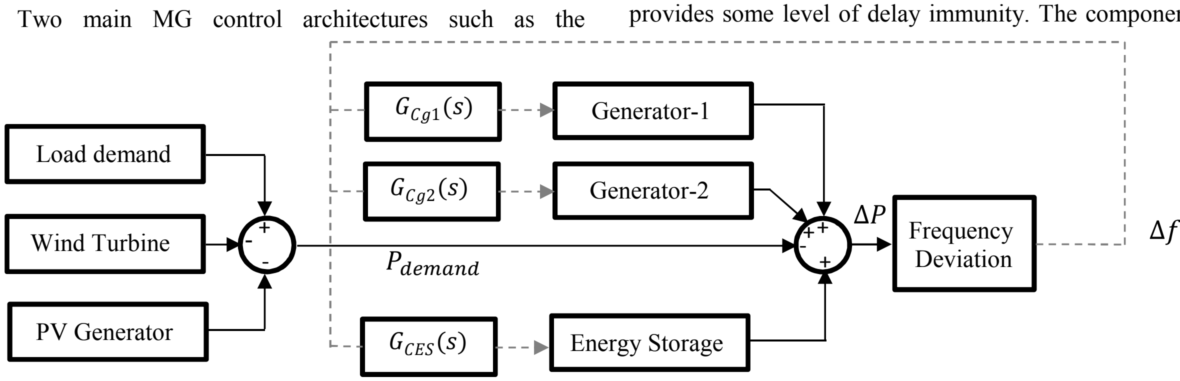

Figure 1. Cyber physical configuration of the microgrid.

MG with low time constant such as Energy Storage (ES) systems are very sensitive to the communication delay [3].

The communication delay in the MG system cannot be removed. Therefore, the overall system should be designed to work with the communication delay. One of the approaches that can be used to decrease the impact of delay is adding delay compensators to the system. The Smith Predictor is used to compensate the delay in different systems [7] [8]. In current study, this concept is used for removing the effect of communication delay in the MG system [9].

In this paper, the Smith Predictor is modified to provide delay compensation to the MG system. The main focus of the study is diminishing the effect of communication delay on the performance of a MG system and keeping its stability in presence of the delay. The considered MG system is composed of two synchronous generators, the ES system, the wind and PV generating systems. The detailed model for the ES is also designed. The Cyber Physical Energy System (CPES) is used to model the control system based on the decentralized architecture and define the control signals of the MG [3]. The CPES model of the MG used in this paper is shown in Fig.1. The CPES with designed delay compensator is simulated in MATLAB/Simulink for delay values. and results illustrate the important role of the compensator to keep the stability of the system for different amount of delays with and without delay compensator. The simulation results show that the impact of delay on the control signals and frequency is significantly decreased. It is worth noting that the proposed predictor based compensator provides robust operation.

This paper is organized as follows. In Section II, the MG model and the cyber-physical model are introduced, and the accurate model of the ES system is proposed in Section III. In Section IV, Smith Predictor is analyzed and the controller is suggested. Simulation results are presented and discussed in Section V, and finally, in Section VI conclusion and future directions are given.

II. System Configuration And Cyber-Physical Model

In this section, the MG model and cyber physical model are introduced. The MG consists of two natural gas generators, one PV, one wind turbine, a load and an energy storage (ES) device. The Fig. 1 shows cyber physical model of the MG. There are two different MG control methods: The centralized architecture and the decentralized architecture. As shown in [2], MG stability and reliability are increased through decentralized control method. The decentralized method based on its configuration and features, is suggested and used in this paper [4]. Each component of the MG has its own controller. Regarding this architecture, it is assumed that each generator and ES device has its secondary and primary control and we need to analyze the effect of delay on each controller. Some studies have done regarding the impacts of communication delay based on cyber physical model on MG stability and reported the range of the stability of system [3], [10], [11], [12].

In order to reach a simple model of the MG, a dynamic model for each components that generates power to supply the local demand is considered. Also, it is assumed that the MG always operates as an islanded power system. The demand power and active power are evaluated as:

$$P_{demand} = P_L - P_{wind} - P_{PV} \tag{1}$$

$$\Delta P = P_{g1} + P_{g2} + P_{ES} - P_{demand} \tag{2}$$

The demand power includes the load demand as a positive load, the PV generation, and the wind turbine, as negative loads. The MG block diagram with its controllers are depicted in Fig. 2 [3].

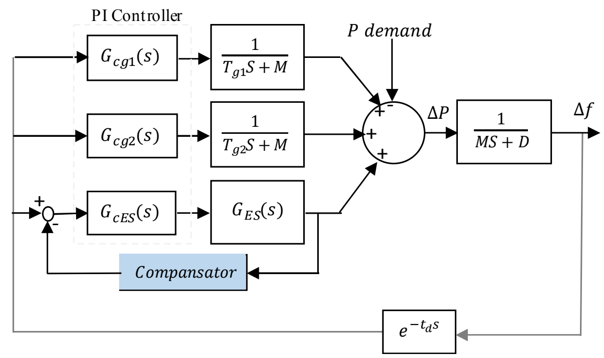

Figure 2. Simulink model of system with the delay.

The low-frequency model is used for natural gas generators with their own time constants [3]. Detailed model is presented and used for the ES which is more sensitive to the communication delay [6]. T_{g1} and T_{g2} is the time constants of the two natural gas generators. It is assumed that the power of generator should compensate the difference in load demand and power supplied by the PV and wind turbine. The relationship between the active power and frequency variation is defined by (3) where *M* is the inertia constant and *D* is the load damping constant [3]:

$$\frac{\Delta f}{\Delta P} = \frac{1}{MS+D} \tag{3}$$

III. The Accurate Model of The Energy Storage System

The dynamics of ES device has the key role in maintaining the stability of the system. The accurate model of the ES is distracted from MG equations [6]. v_{id} and v_{iq} are voltages of inverter's output in d- and q-axis. The ES connected to the MG through the filter and the transformer. The (4) -(7) can be written for the system:

$$\dot{v}_{cd} = \frac{1}{C_f}[i_{fd} - a i_{td} + \omega C_f v_{cq}] \tag{4}$$

$$\dot{v}_{cq} = \frac{1}{C_f}[i_{fq} - a i_{tq} - \omega C_f v_{cd}] \tag{5}$$

$$i_{fd} = \frac{1}{L_f}[v_{id} - v_{cd} - R_f i_{fd} + \omega L_f i_{fq}] \tag{6}$$

$$i_{fq} = \frac{1}{L_f}[v_{iq} - v_{cq} - R_f i_f - \omega L_f i_{fd}] \tag{7}$$

where C_f and α are representing the capacitor of filter and the ratio of transformer, respectively. The primary control of the ES consists of an inner current feedback loop, and an outer voltage feedback loop [6]. The simple model is used for modeling of the battery and inverter. The energy storage system block diagram for d-axis is depicted in Fig. 3.

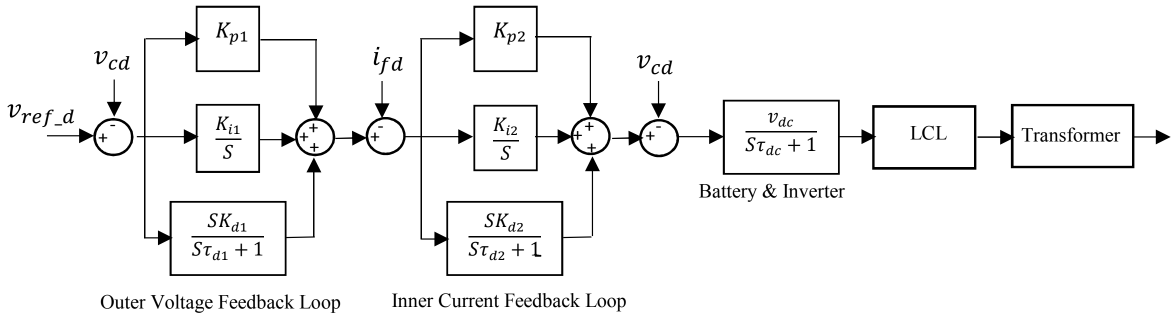

Figure 3. The accurate model of energy storage system.

IV. The Smith Predictor Specific Structure and Communication Delay

The Smith Predictor is a method to compensate the delay of a control system. This method can be used for different applications such as mechanical systems [7]. The main concept in the Smith Predictor is how to reduce the impact of delay component in the system [8]. In current study, this concept is used for removing the effect of communication delay by modifying the main form of the Smith Predictor. Fig. 4 shows the block diagram of the compensator system that is suggested in this paper, where $\tilde{G}(s)$ denotes the estimation of $G(s)$.

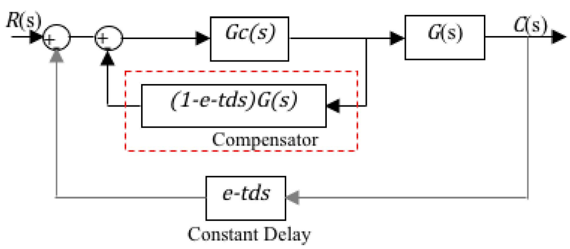

Figure 4. The Smith Predictor block diagram with communication delay.

Different models are used for the prediction of the behavior of the real system. The step response method is used to estimate the model of the system in this paper [8]. By making close the response of $G(s)$ to the response of $\tilde{G}(s)$, the impact of delay will be decreased according to (8):

$$\frac{C(s)}{R(s)} = \frac{G_c(s)G(s)}{1+G_c(s)\tilde{G}(s)+G_c(s)e^{-t_dS}\left(G(s)-\tilde{G}(s)\right)} \quad (8)$$

V. Simulation Results

The cyber-physical model of MG with its controllers given in Fig. 1 is simulated using MATLAB/Simulink. The simulation parameters are defined in Table I. The simulations studies are done in three steps.

Firstly, the system is simulated without any delay and the results are shown in Fig. 5. As it is seen, the system provides good performance with lower frequency deviation. Then, the delay is injected to the feedback line and the performance of the system is investigated for different delay time. It is seen that the delay at the feedback loop generates some oscillations, and when the delay reaches 30 ms, the system becomes unstable. The amount of the threshold depends on the dynamic of system and communication platform.

TABLE I. Simulation parameters for the microgrid system.

Simulation Parameters		
Definition	***Symbol***	***Value***
Inertia Constant	M	0.008
Damping Constant	D	0.15
Time constant of Generators	T_{g1} and T_{g2}	8
Time constant of ES	T_{ES}	0.3
PID Parameters of Generators	K_{ig}& K_{pg}	3.4 & 5
PID Parameters of ES	K_{iES}& K_{pES}	0.5 & 3.1

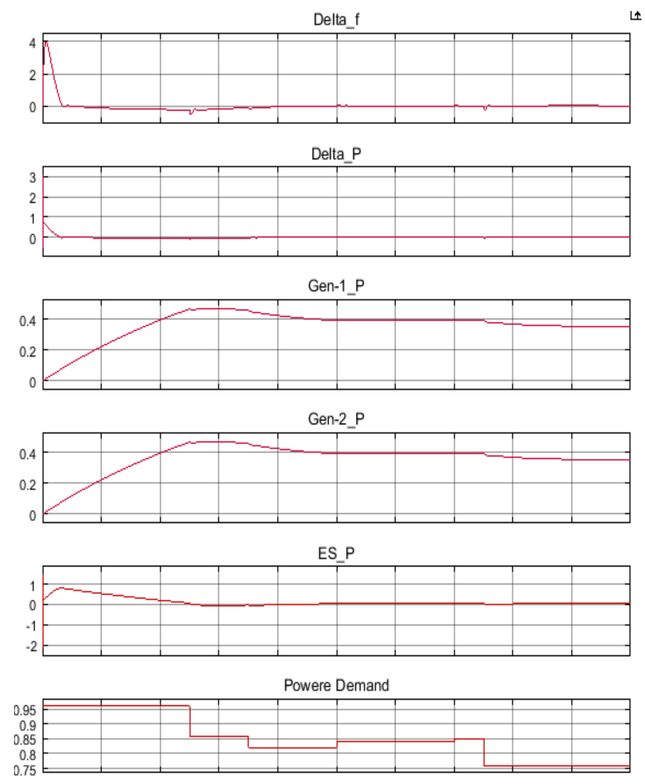

Figure 5. The simulation results without delay.

The responses of the system for 30 ms delay are shown in Fig. 6. The simulation results show that the delay has more impact on ES than generators therefore, compensator is added to the control line of ES. It is important to know that the time constant of ES is lower than the generators. Finally, the simulation is repeated with the new predictive controller. In this case, it is assumed the delay is constant and the step response technique is used to estimate the model of ES.

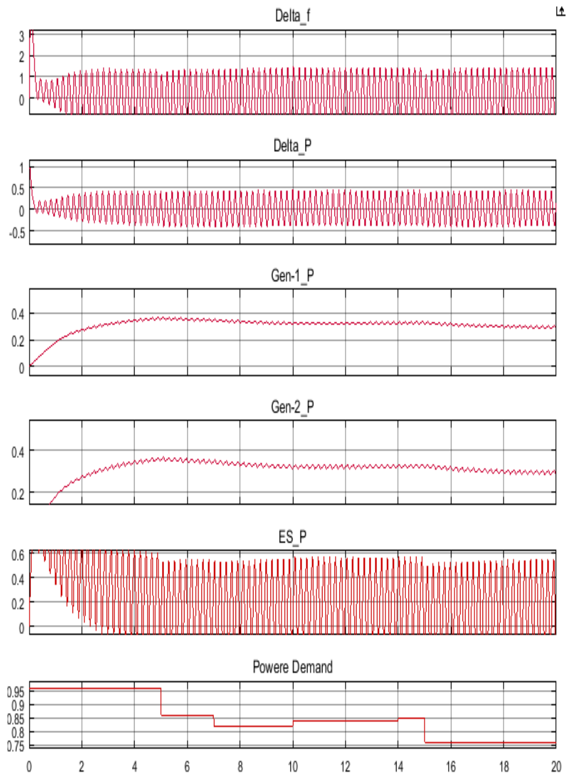

Figure 6. The Simulation results by injecting 30 ms delay at feedback (without using the compansator).

In addition, the simple model is considered for load frequency transfer function. The results are depicted in Fig. 7. As it is seen, the proposed approach significantly improves the system performance in case of delay. Fig. 8 illustrates the frequency deviation with injected delays into the feedback line without using any controller. The responses are not acceptable and system becomes unstable.

Fig. 9 shows, the effect of the compensator to maintain the frequency deviation in acceptable range with injecting 30ms, 50 ms and 100 ms delay into the feedback line. This results are comparable with frequency deviation in Fig. 8. While in the conventional system a 30 ms delay causes non-damping oscillation on frequency deviation, it is seen from Fig. 7 that the proposed controller with delay compensation can work with 120 ms delay.

VI. Conclusion And Future Work

In this study, a compensator based on predictive controller is presented for the MG control system to remove the effect of the communication delay. The proposed system with the compensator is simulated. The obtained results show that the new approach can increase the stability of system even in case of communication delay. The next step is the hardware implementation of controller for validation of results. Based on the impact analysis, we can also propose a new controller to decrease the effect of time-varying communication delay. Using machine learning techniques for estimation of the model parameters is suggested for increasing the accuracy of compensator.

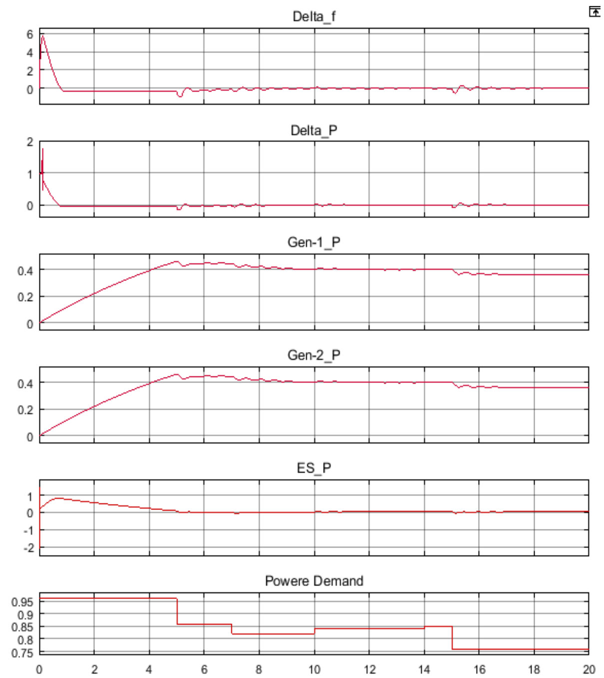

Figure 7. The simulation results by injecting120 ms delay at feedback (with using the compansator)

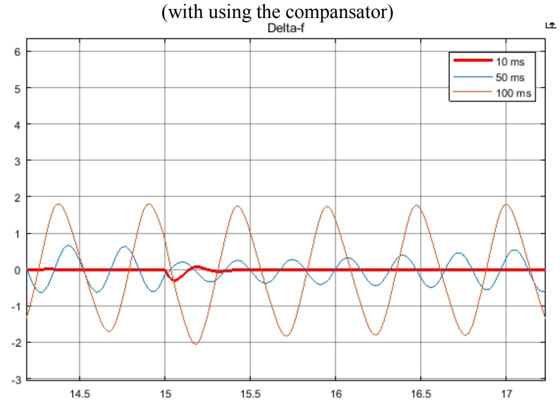

Figure 8. The frequency deviation of system with 10ms, 50ms and 100 ms delay in feedback (without using the compansator).

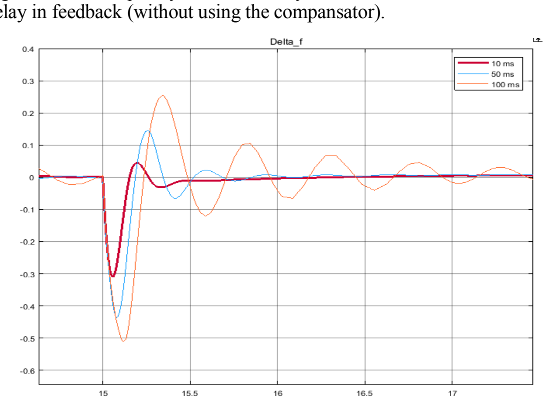

Figure 9. The frequency deviation of system with 10ms, 50ms and 100 ms delay in feedback (With using the compansator).

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