Mitigation of High Frequency Forced Oscillation through Renewables

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***Abstract*— As a consequence of the ongoing growth of power systems and the use of power electronic equipment, forced oscillations are becoming one of the major issues that threaten power system stability and secure operation. Forced oscillations can have detrimental influences, such as reducing transmission capacity or even resulting in outages. A renewable power plant, which is close to the forced source, can be used to modulate its active power and reduce high frequency oscillations. Through the study on a 13-bus system in PSCAD, this paper proposes a controller which can be placed in a renewable plant close to the forced source. The proposed controller contains a high pass filter, a control gain, and phase shift blocks and it can damp the forced oscillation more than 80%.**

Keywords*— forced oscillation, damping control, high frequency oscillation, renewable.

I. INTRODUCTION

Forced oscillations in power systems are sustained oscillations caused by outside inputs to the system that can occur at different frequencies and can happen for numerous reasons like cyclic loads [1], low speed diesel generator [2], nuclear accelerator [3] and badly tuned generator controller [4]. Low Frequency oscillations occur at around 0.5 Hz to 3 Hz whereas high frequency oscillations which are known as sub-synchronous resonances occur with a frequency of 5 to 55 Hz [5]. Both types of oscillations can severely jeopardize grid stability. Multiple times North American Power System encountered with forced oscillation with a range of 0.2 to 2 Hz which often made electrical equipment severely damaged. [6] A thermal plant in Central China Grid experienced forced oscillation with 0.7 Hz initial oscillation frequency in 2008 due to its asynchronous connection and to handle that 2 minute's sustained oscillation a 110 kV transmission line needed to be cut off [7]. A malfunctioned steam extractor control valve at Nova Joffre cogenerating plant in Alberta, Canada initiated 20 MW peak to peak 0.27 Hz oscillations which sustained for 5 minutes. [8] On January 11, 2019, a forced oscillation event took place at a combined cycle power plant in Florida due to a faulty input to a control system [9]. This 18-minutes long oscillation endangered the operation of the entire power systems and caused severe instabilities and the plant operator had to manually remove the unit from service. Damping inter-area oscillations is essential for preserving a secure and reliable electricity grid. Oscillation in power systems can have catastrophic effects if it is not controlled, as was the case in 1996 when there were blackouts across western North America [10].

Several researchers performed investigations on mitigation of inter-area oscillations. Historically Power System Stabilizers (PSSs) using local measurements or with the help of remote signals have been considered as an effective remedy to increase damping ratio of natural oscillation [11]. To mitigate forced oscillation, VSC-based FACT devices were proposed in [12-14] as Voltage source converter connected to long transmission line often causes forced oscillation. Unlike natural oscillation, the best solution to forced oscillation is to identify the source and then disconnect it.

Lately, with the development of PMU technology, there has been a resurgence of interest in the research, comprehension and detection of forced oscillations. [15]. Many source location algorithms have been proposed to address the mitigation of forced oscillation [16]. However, due to limited PMU it is difficult to locate source quickly and hence it is advisable to use a controller to suppress the oscillation to a safe level before the source is located [9] As a consequence, researchers have investigated on designing optimum controller that can suppress oscillation significantly. Energy storage devices have the potential to modulate active power of the system [22] Authors of [17]-[20] performed research on forced oscillation in western interconnection and proposed a wide area damping controller which can modulate the active power flow of PDCI. Authors of [21] performed Grid vulnerability analysis on a synthetic Texas power system model and proposed a damping controller through IBRs. Controllers can be implemented in the BESS model nearby forced location. However, in a system where sufficient renewables are present, it is not necessary to install BESS model and renewable units can be an ideal location to place the controller. The main concept of using these controllers is to automatically induce a second oscillation into the grid which cancels the impact of the forced oscillation without the need for locating the source [23].

This paper is a simulation-based case study on a 13-bus model developed in PSCAD to analyze the mitigation on forced oscillation. At first, forced oscillation event has been mimicked in a unit of that grid model with a periodic disturbance and then the control strategy has been validated.

This paper examines the validity of existing controller to damp high frequency oscillations and by exploring the actuators (PV model) behavior, it is found that the actuator does not respond to high frequency oscillation as sufficiently as to the low frequency oscillations. Hereby, the existing controller is no longer appropriate, since it does not consider the controller impact on both high frequency and low frequency, which in fact limits its damping performance. This paper proposes a new control design which can sufficiently damp high frequency as well as low frequency disturbances.

The rest of this paper is organized as follows. Section II provides a summary of the methodology, Section III introduces existing controller limitation, Section IV presents modified controller design, and Section V provides the conclusion.

II. METHODOLOGY

A. *Forced Disturbance*

A detailed PSCAD model of a small grid been used for this study. The model consists of five synchronous generators and four renewables and total load is set as 43.9 MW. Forced oscillation can be mimicked in simulations by changing the active power set point of a generator governor model or changing the voltage set point of the exciter model [9]. In this case study, active power of governor has been modulated with a sinusoidal waveform. The sinusoidal waveform is defined as:

$$\Delta P(t) = A \sin(2\pi f t) \tag{1}$$

where f is the forced oscillation frequency, A is the amplitude of the sinusoidal wave, and $\Delta P(t)$ is the active power that is added to the governor active power set point.

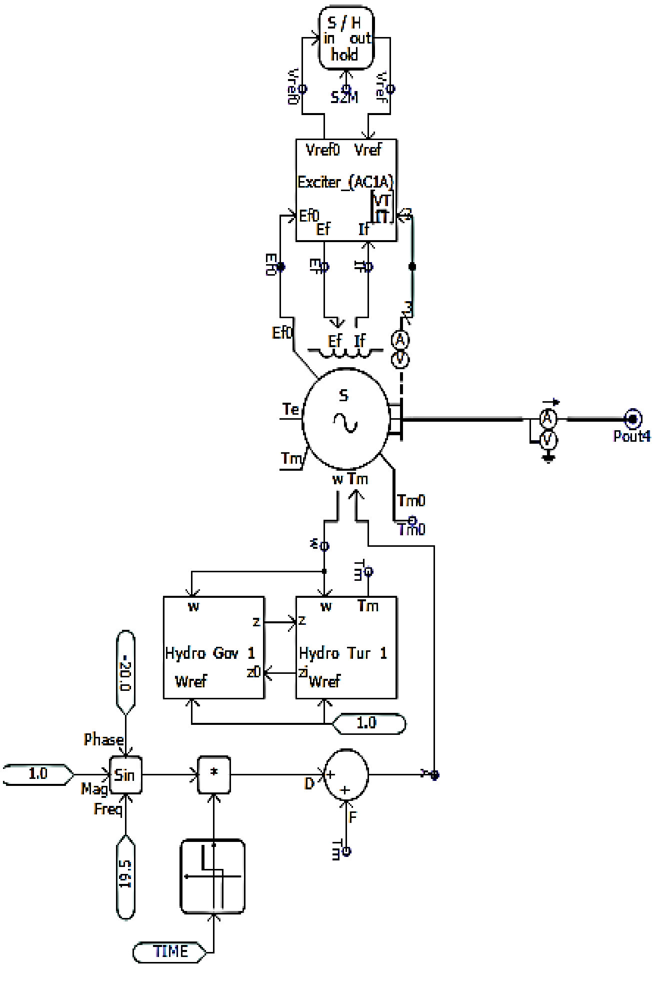


Fig 1. Forced Disturbance Injection

The sinusoidal disturbance was injected after 30 seconds. It was added through the governor of a 1.97 MVA synchronous generator. It has been observed that the 19.5 Hz 1V disturbance introduces 20 mHz peak to peak oscillation in the forced source and depending on the distance from the forced source, the oscillation spreads around other generation units. If a unit is close to the forced source, oscillation in that unit is large.

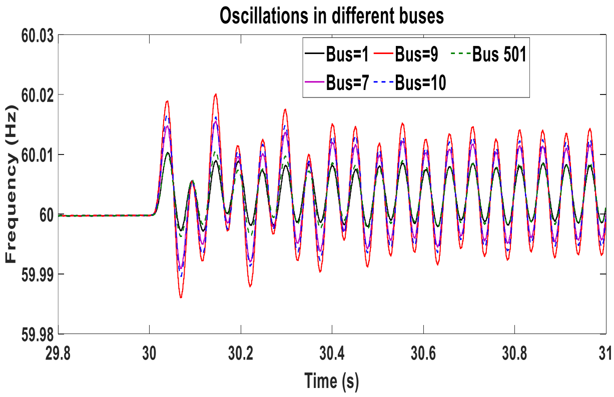


Figure 2: Oscillation in different buses in 19.5 Hz forced disturbances

B. *Oscillation Suppression*

To mitigate the oscillation created by the forced disturbance, a droop controller can be placed in a nearby PV unit. Figure 3 illustrates the basic method the controller uses to reduce oscillations.

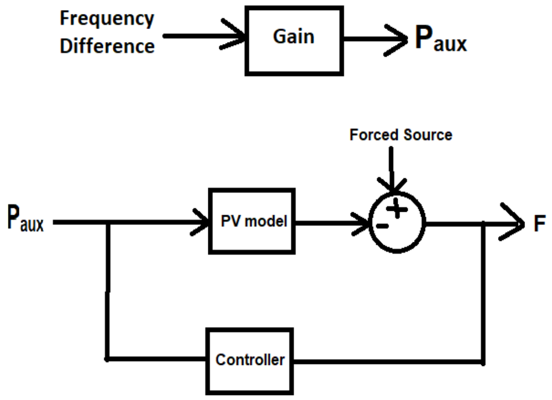


Figure 3: Control Method for Suppressing Oscillation

The controller takes the frequency of a nearby high voltage bus as the input and compares it with the nominal frequency (60 Hz). The error signal then goes through a gain block to generate auxiliary power setpoint (P_{aux})of the PV unit. This auxiliary power setpoint modulates the active power setpoint of the PV unit.

The controller gain needs to be negative to create an opposing force with respect to the forced disturbance. By proper tuning of the gain, damping performance is controlled.

III. EXISTING CONTROLLER & LIMITATION

The conventional controller is a droop controller with washout block, a first order filter block, a control gain block and phase shift blocks. Figure 4 illustrates the existing controller scheme. The difference between the frequency of a neighbor bus and the nominal frequency ∂F is taken as a input and flows through a closed loop. In the washout block, time constant T=10s is used.

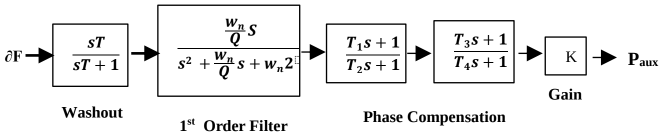


Fig 4. Existing Control Scheme

The conventional controller uses a 1st order filter keeping quality factor Q=1. Phase compensation blocks are used to tune the phase angles of controller and the forced source. In the phase compensation blocks, $T_1=T_3$ and $T_2=T_4$.

This existing controller can mitigate low frequency oscillations significantly but in case of high frequency oscillations, the controller has some limitations. In this paper, 0.67 Hz disturbance has been used to mimic low frequency disturbance and 19.5 Hz frequency disturbance has been used to represent the high frequency ones. Figure 5 shows that the controller can damp the low frequency oscillation by 90% in case of 0.67 Hz disturbance.

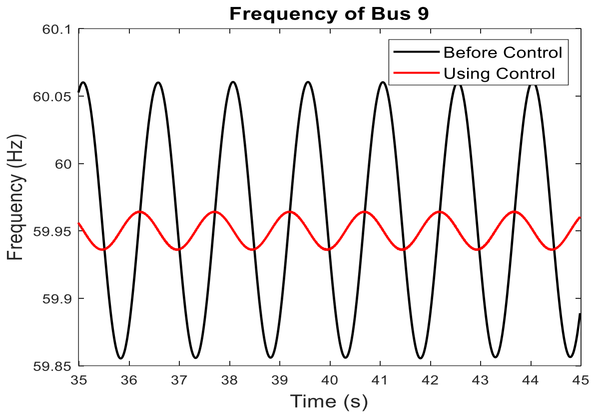


Figure 5: Oscillation in the forced source with 0.67 Hz disturbance.

However, in case of high frequency disturbance the controller is not fast enough to damp the oscillations more than 65% Figure 6 shows the case with 19.5 Hz disturbance where oscillations in different buses before and after the control have been compared. Among the 13 buses of the system, those which are connected to synchronous generators have been demonstrated for simplicity. It can be seen from Figure 6 that damping of 62-64% has been achieved in those buses.

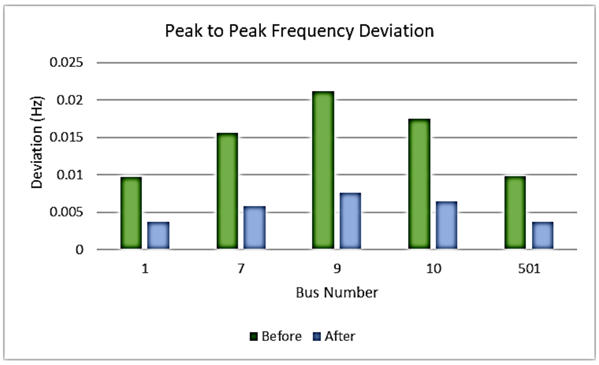


Figure 6: Frequency Deviation in different buses

By analyzing the results of low frequency and high frequency disturbance results, it can be said that the PV model is similar with a low pass filter and so it has limited capability to damp high frequency oscillation. A bode plot analysis has been done for verifying this low pass characteristics which is displayed in figure 7. From the bode plot it can be seen that at 0.67 Hz frequency response can reduce to around 95%(-26dB) whereas at 19.5 Hz the frequency response can reduce to 70%(-12db).

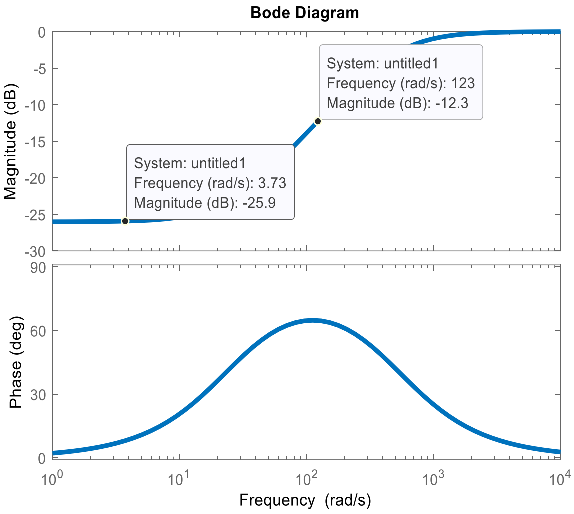


Figure 7: Bode Plot Results

The bode plot results are consistent with the oscillation simulation results as for low frequency disturbance damping of 90% and for high frequency disturbance damping of 60% could be achieved.

IV. Modified Controller Design

A. *Controller Scheme*

Due to the limitation of the existing controller to damp high frequency oscillation, it is necessary to do modification in the scheme.

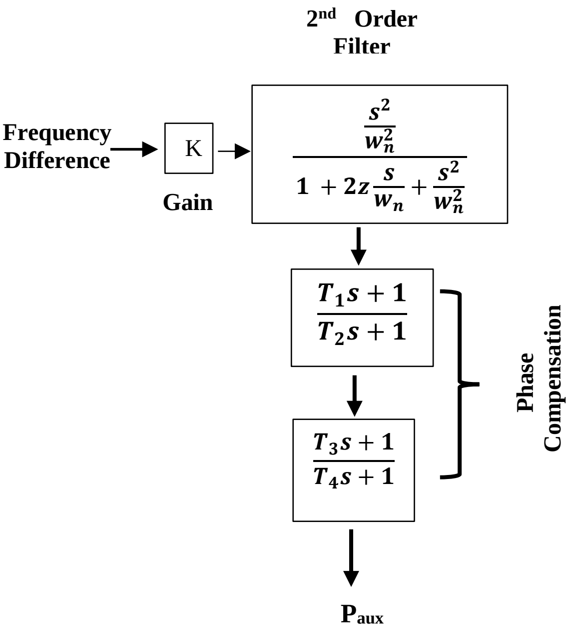
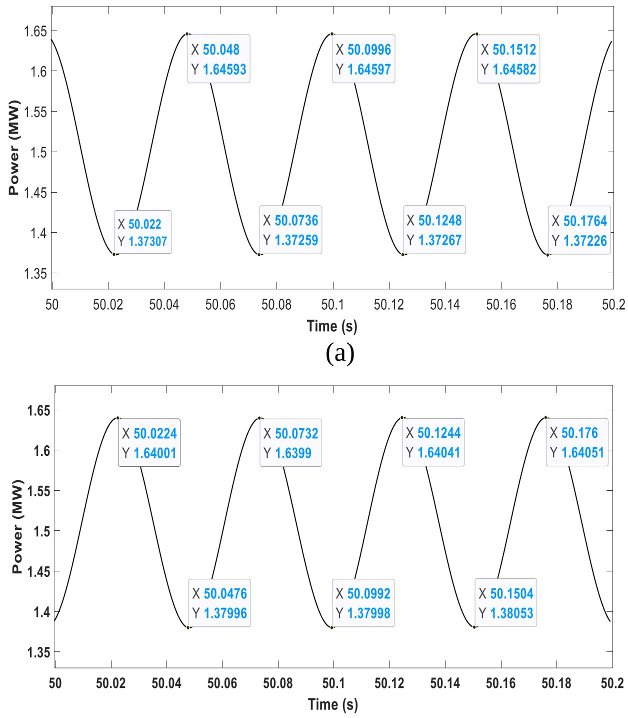


Figure 8: Modified Controller Scheme

Figure 8 illustrates the new controller scheme which consist of a control gain block, a 2nd order filter block and phase compensation blocks. The second order high pass filter provides the PV capability to damp high frequency oscillation.



(a)

(b)

Fig. 9: Oppositely Shifted Active Power injected in the (a) Source and (b)Controller

In the filter block, 2z is an indicative of the quality factor Q. ω_n needs to be set as the forced oscillation frequency. For 19.5 Hz disturbance, ω_n is set as 122.52 rad/s. The gain K needs to be properly tuned to achieve the best damping. The phase compensation blocks are used to slightly modify the phases of controller injected active power with respect to source injected active power.

B. *Controller Performance*

The modified controller scheme if placed in a PV unit adjacent with the forced source, can damp the high frequency oscillation significantly. In this study, a PV unit which is very close to the source location has been chosen for placing the controller. The impedance between the source and the PV unit is 0.035+0.12j.

To mimic high frequency forced disturbance, a 19.5 Hz 1V sinusoidal disturbance has been injected through the governor of the generation unit at bus 9. The forced disturbance injects 0.28 MW active power to that bus. The controller produces 0.27 MW active power in opposite direction to damp the oscillation produced by the disturbance.

The phase shift blocks are used to precisely tune the controller injected power with the source injected power.

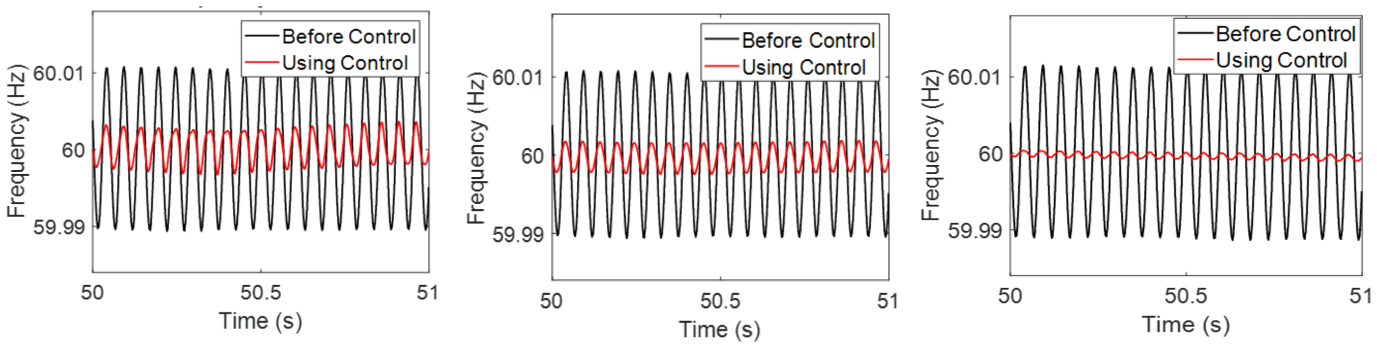
C. *Impact of z*

The controller performance can be further improved by modifying the z parameter in the filter block. z parameter is an indicative of quality factor Q. Figure 10 shows that with reduced value of z, the damping capability increases. Figure 10(a) illustrates the controller performance with z=0.5. In the phase shift blocks, T_1=T_3=0.0055 and T_2=T_4=0.0122 have been used for 45 degree phase adjustment and Gain K=-440 have been used for stability. In this case 75% damping could be achieved in the forced source.

Figure 10(b) illustrates the controller performance with z=0.2. In the phase shift blocks, T_1=T_3=0.0057 and T_2=T_4=0.0117 have been used for 40 degree phase adjustment and Gain K=-248 have been used for stability. In this case 82% damping could be achieved in the forced source.

Figure 10(c) illustrates the controller performance with z=0.2. In the phase shift blocks, T_1=T_3=0.0047 and T_2=T_4=0.0141 have been used for 60 degree phase adjustment and Gain K=-150 have been used for stability. In this case 96% damping could be achieved in the forced source.

. It is distinctly observable that the oscillation significantly reduced after using smaller value of z in the proposed control scheme. However, there is a limit to how far z may be reduced. As quality factor Q determines how sharply the controller is tuned to frequency, setting it to a very small value might make the controller very sensitive. In that case the controller might not work well if a slightly different frequency of disturbance occurs. For this reason, setting z to a moderate value is recommended. Even though Figure 10(c) demonstrates that damping has reached its maximum, it is difficult to adjust the controller power to be precisely out of phase with the source power when z is so small. Furthermore, setting z to such a low value would make the controller extremely susceptible to other frequencies, which is not practical.



(a)

(b)

(c)

Fig. 10: Oscillation in 19.5 Hz forced disturbance with the proposed controller while keeping (a)z=0.5, (b)z=0.2 and (c)z=0.01

Considering these issues and analyzing the simulation results, z=0.2 is proposed for the controller which can offer 82% damping in the forced source.

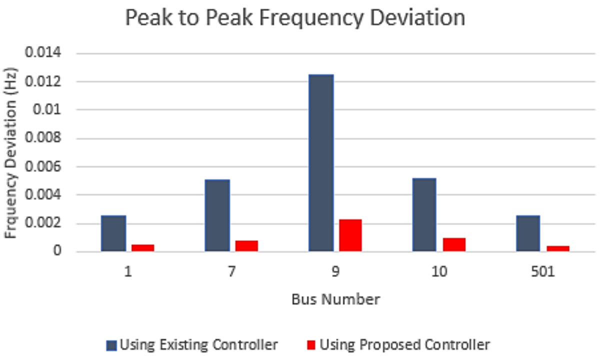


Fig 12: Peak to peak frequency deviation before and after using proposed scheme.

Figure 12 compares between the peak to peak frequency deviation using the existing controller and proposed controller at 19.5 Hz forced disturbance. The proposed controller provides remarkable improvement in damping performance.

V. CONCLUSION

This paper addresses the challenges of mitigating high frequency forced oscillation with the existing controller scheme. It proposes a innovative control structure to better improve the damping performance of high frequency oscillations in power grid. When a forced oscillation event occurs, the oscillation produced can be tackled by placing this controller in a nearby renewable unit before the source is completely identified and removed. The proposed controller performance has been validated through a 13-bus power grid model in PSCAD. All of the buses in the system could achieve 81%-84% damping with the proposed controller, compared to 60% damping with the conventional controller. The proposed controller can minimize the control impact on the system dynamics at other frequency bands and is effective in damping both low and high frequency oscillations.

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