Power Frequency Control

Assignment 1 - Group 4

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Module

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1 INTRODUCTION

This assignment aims to analyse the power frequency response of an isolated area system and then a two-area system when dealing with small disturbances. These power system simulation models are designed in Simulink to observe the variations in system frequency to be studied for variations in the system load for the isolated system.

In the interconnected system, a linear model of two power system areas is connected by an interconnector (tie-line), which is used to examine the variation of area frequency and tie-line power flow after load disturbance. These system parameters are provided as shown in Table 1.

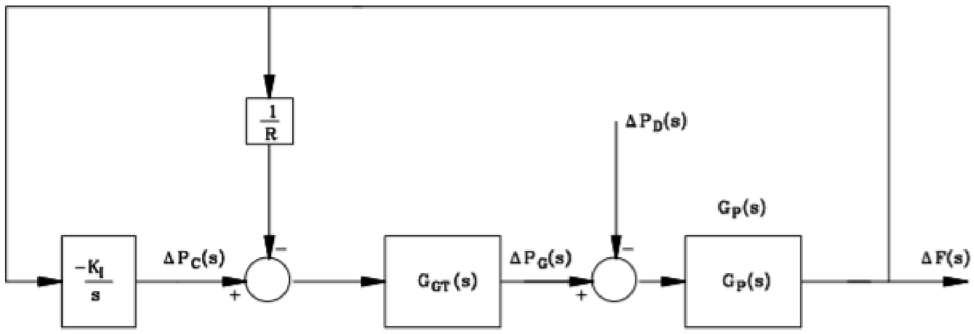

Figure 1: Block Diagram for a single area

1.1 SYSTEM DETAILS

The system details that will be used in this experiment can be seen below in Table 1.

Parameter	Area A	Area B
T_p / K_p	0.2	0.12
D = $1/K_p$	0.01	0.008
T_G	0.5	0.5
T_T	0.1	0.1
R	4% = 2.0 Hz/p.u. MW	4% = 2.0 Hz/p.u. MW
K_i	0.2	0.1

Table 1: System Details

2 METHODOLOGY

1. A Simulink model was developed for an isolated area without the interconnection and the power frequency control (integral control) on areas A and B and the variation in frequency was determined when a load disturbance of -0.05 p.u. was used for area A and +0.03 p.u. was used for area B.

2. Power frequency control (integral control) was added to the Simulink model and step (1) above was repeated.

3. The Simulink model from step (2) was used to plot the response of the system frequency for a step change in system demand for 5 different values of integral gain. The value of K_i that caused instability was found.

4. The time (clock) error was calculated and found by selecting one of the values of integral gain from before and using a step change in demand of -0.05 p.u.

5. A Simulink model was developed to represent a two-area system with the interconnector in place but without the ACE control. The response in area frequency and power flow between the areas for a step change in area A of -0.05 p.u. and +0.03 p.u in area B were plotted.

6. Then, ACE control was added to the model in step (5) to ensure that both the power flow between the areas and the frequency returned to their pre-disturbance values. Appropriate values were selected for K_i and B and a reasonable response was obtained. Later responses were plotted for cases of high values of K_i and low values of B and then low values of K_i and high values of B. These were compared and discussed.

7. The parameters for a power frequency control model were discussed and researched.

8. Lastly for the additional element, the time error was discussed.

3 Results

The results section goes through seven important investigations that help to examine the power frequency control of an isolated area and a two-area system when there is subject to small disturbances. The results are recorded in forms of plots and calculations.

3.1 [A] The variation in frequency in each area

The variation in frequency in each area is determined when a load disturbance is injected into each of the areas. This is done without the interconnection and without the power frequency control.

3.1.1 Variation in frequency in area A when Load Disturbance = -0.05 p.u.

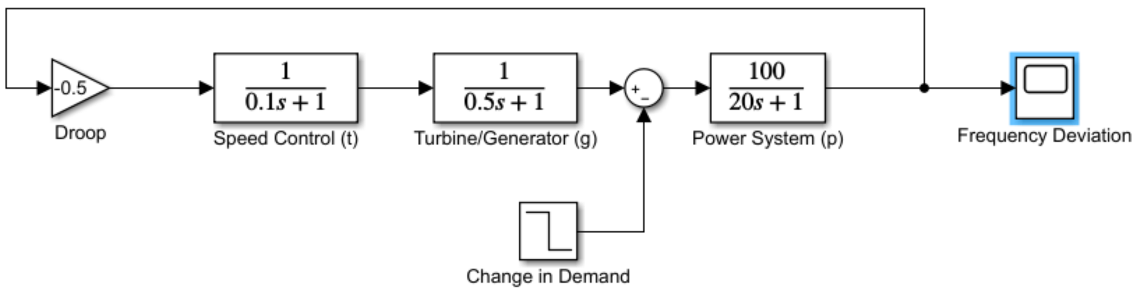

Figure 2: Single control area for area A

The variation in frequency in area A can be seen below in Figure 3 when a load disturbance of -0.05 p.u. is injected. The result of this plot is that the change in frequency drops fast and the change in frequency is above zero.

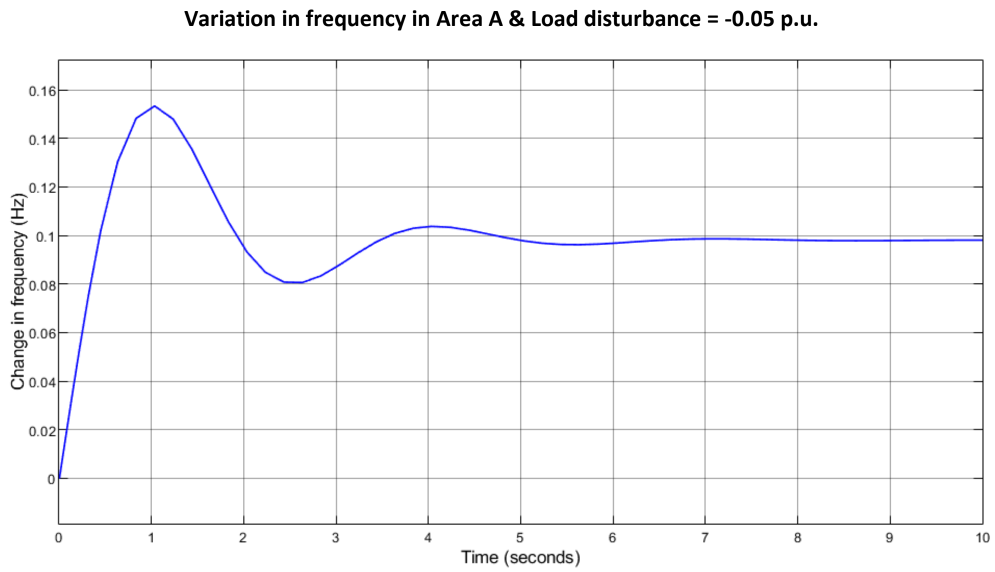

Figure 3: Variation in frequency in area A & Load disturbance = -0.05 p.u.

3.1.2 Variation in frequency in area B when Load Disturbance = +0.03 p.u.

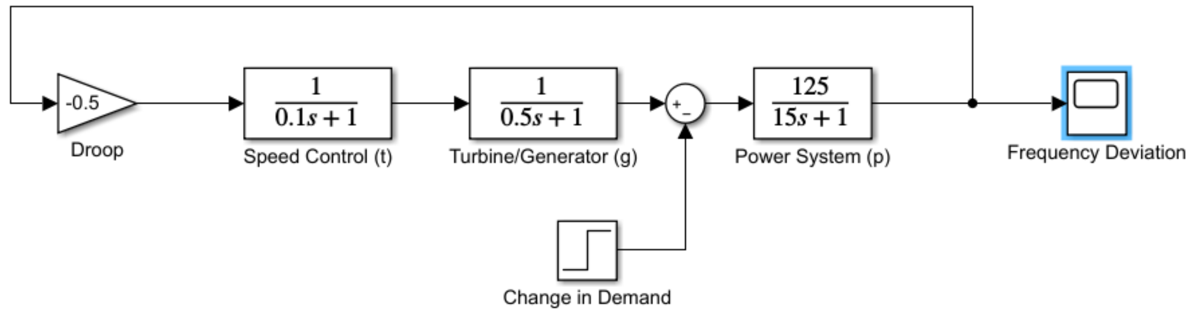

Figure 4: Single control area for area B

The variation in frequency in area B can be seen below in Figure 5 when a load disturbance of +0.03 p.u. is injected. The result of this plot is that the change in frequency drops fast and the change in frequency is below zero.

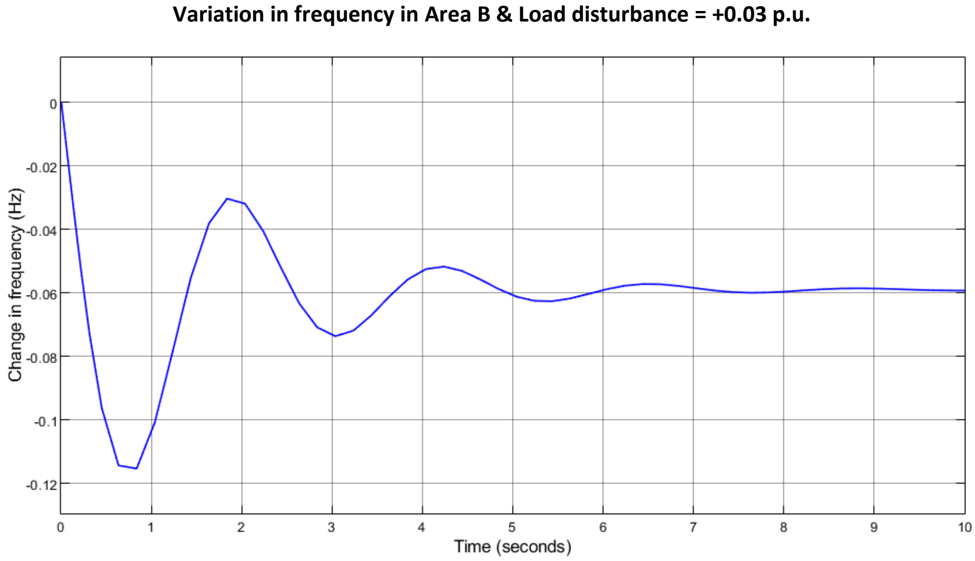

Figure 5: Variation in frequency in area B & Load disturbance = +0.03 p.u.

The steady-state frequency change can be seen below and can be determined by applying the Final Value Theorem.

$$\Delta f = \frac{-M}{D + 1/R} = -\frac{M}{\mathrm{b}}$$

There are 3 sources of power in the system to meet an increase in demand which is accompanied by a frequency drop. They are a reduction in load due to a decrease in frequency, an increase in generation because the speed control loop and the change in kinetic energy of the rotating rotary. Here, as the frequency drops, the energy is release by the machines and it provided a short-term source of power.

3.2 [B] INCLUDING POWER FREQUENCY CONTROL - INTEGRAL CONTROL

In this section power frequency control, which is the integral control is added to area A and area B using the same parameters from the previous step (A).

3.2.1 Variation in frequency in area A when Load Disturbance = -0.05 p.u.

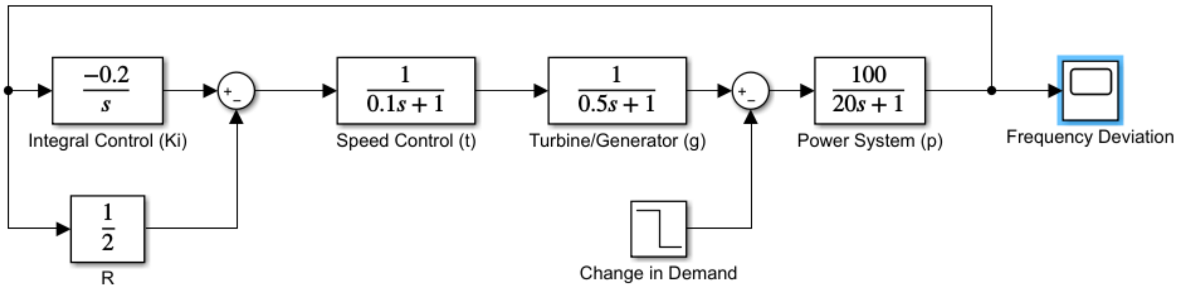

Figure 6: Single control area with integral control for area A

The variation in frequency in area A can be seen below in Figure 7 when a load disturbance of -0.05 p.u. is injected and the integral control is used. The result of this plot is that it has a small number of oscillations, and these oscillations decrease with time, and therefore it is in a stable condition, when K_i is 0.2. More oscillations would lead to a faster repose and if the integral gain, K_i exceeded the critical value it would cause instability.

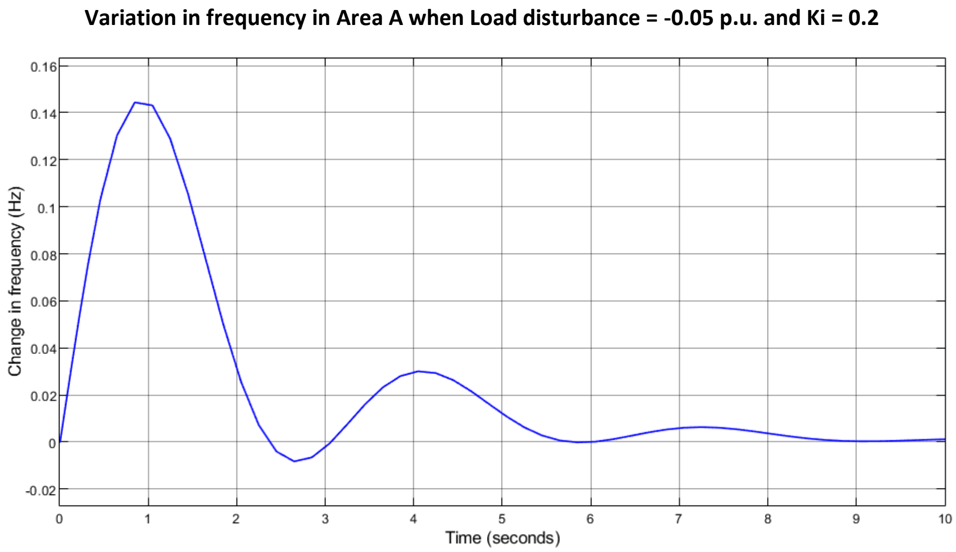

Figure 7: Variation in frequency in area A when Load disturbance = -0.05 p.u. and Ki = 0.2

3.2.2 Variation in frequency in area B when Load Disturbance = +0.03 p.u.

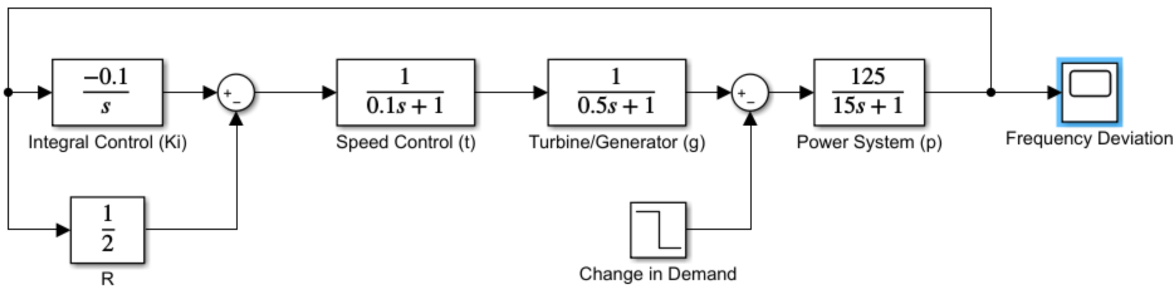

Figure 8: Single control area with integral control for area B

The variation in frequency in area B can be seen below in Figure 9 when a load disturbance of +0.03 p.u. is injected and integral control is used. The result of this plot is that it has a small number of oscillations, and these oscillations decrease with time, and therefore and it is in a stable condition, when K_i is 0.1.

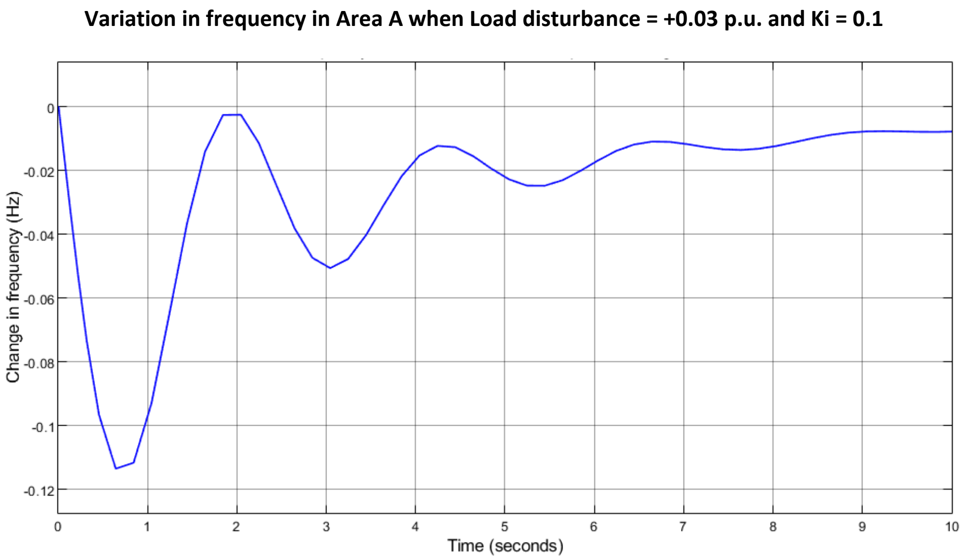

Figure 9: Variation in frequency in area B when Load disturbance = +0.03 p.u. and Ki = 0.1

3.3 [C] DETERMINE THE VALUE OF KI THAT CAUSES INSTABILITY IN THE SYSTEM

To figure out what K_i value causes instability in the system, the plot of the response of the system frequency for a step change in system demand for 5 values of integral gain, K_i is observed for area A.

3.3.1 Integral gain (Ki) is 0.3

When K_i = 0.3, the system is stable with a small number of oscillations that decrease with time, until the oscillations are not visible anymore.

Variation in frequency in Area A when Load disturbance = -0.05 p.u. and Ki = 0.3

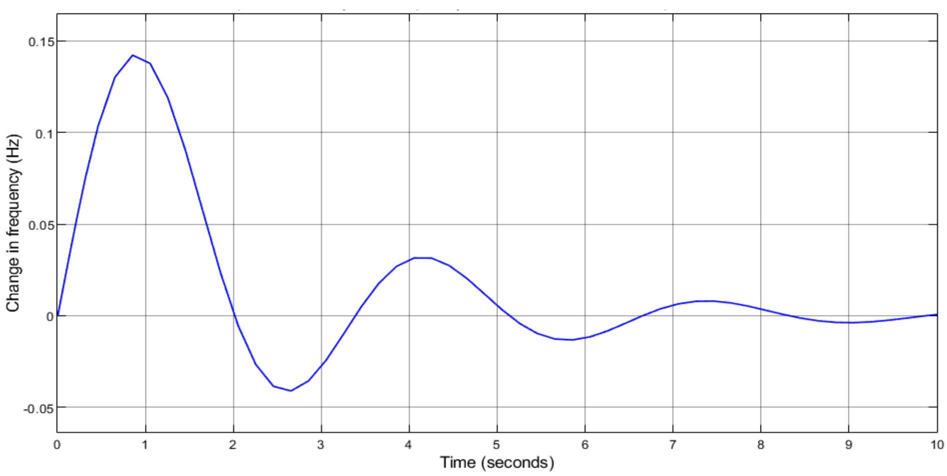

Figure 10: Effect of integral control, Ki = 0.3

3.3.2 Integral gain (Ki) is 0.5

When K_i = 0.5, the system is still stable, but the peaks of the oscillations increase as the integral control, K_i also is increased, this means that it is a faster response then before.

Variation in frequency in Area A when Load disturbance = -0.05 p.u. and Ki = 0.5

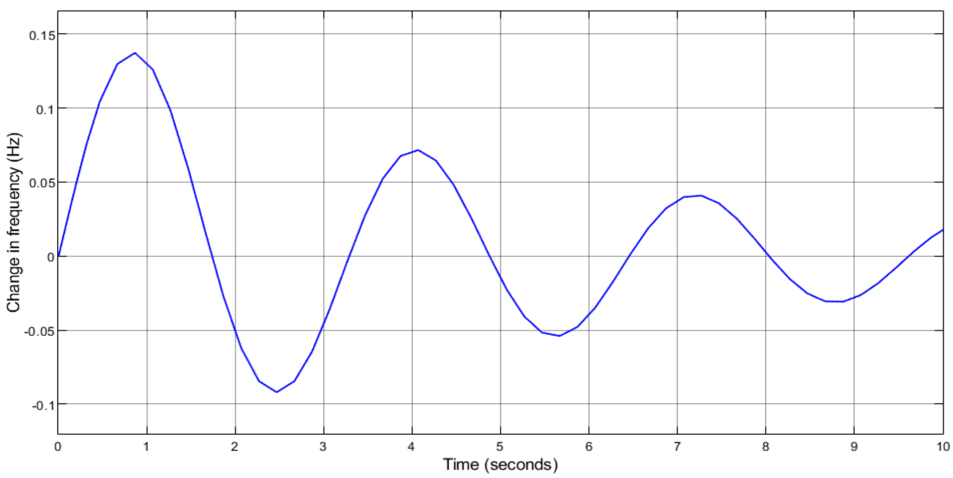

Figure 11: Effect of integral control, Ki = 0.5

3.3.3 Integral gain (Ki) is 0.6

When K_i = 0.6, the system is still stable, but the peaks of the oscillations increase even more as the integral control, K_i is also increased, this means that it is a faster response then before and it will reach instability soon.

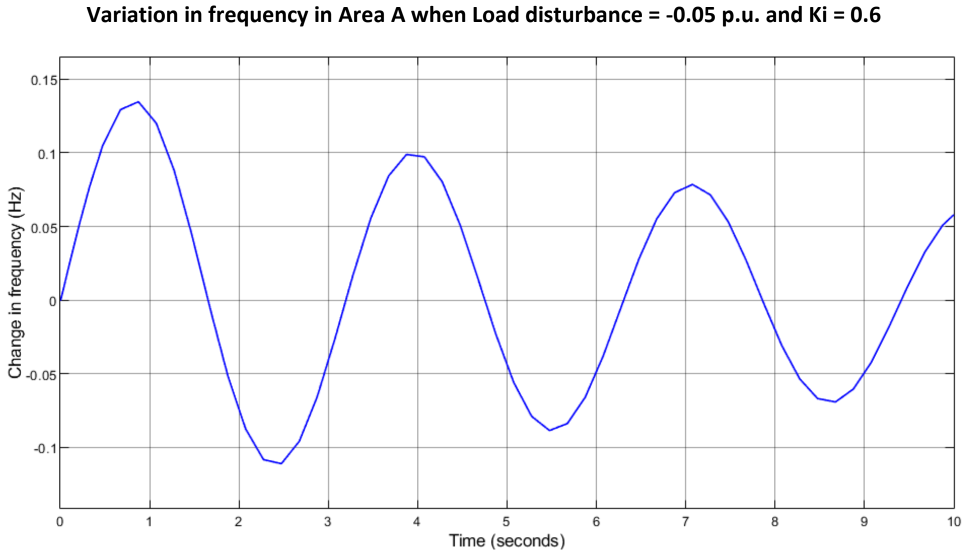

Figure 12: Effect of integral control, Ki = 0.6

3.3.4 Integral gain (Ki) is 0.7

When K_i = 0.7, the system becomes unstable and the critical value is reached and exceeded, the peaks of the oscillations are increased even more as the integral control, K_i also increased, this means that there is a faster response then before and has reached instability. The plot will increase and oscillate forever.

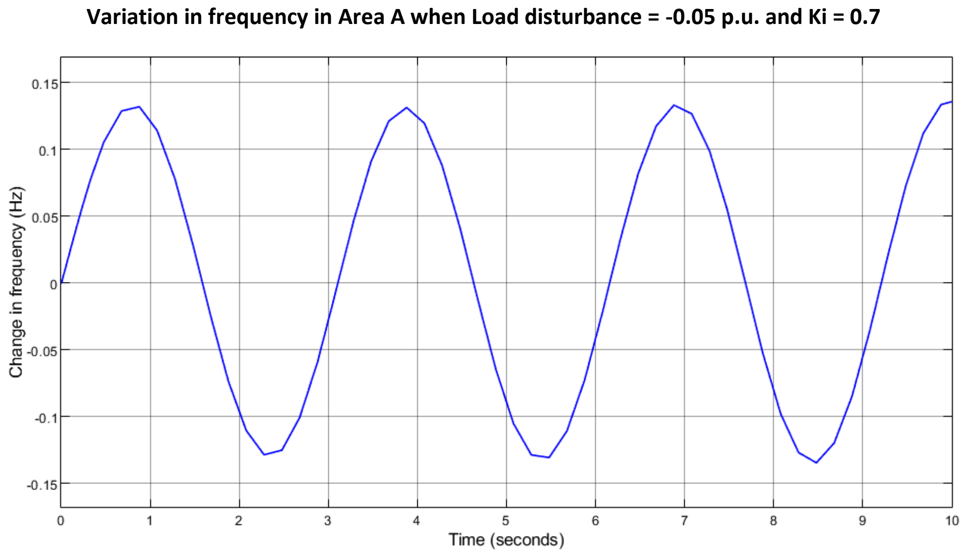

Figure 13: Effect of integral control, Ki = 0.7

3.3.5 Integral gain (Ki) is 0.8

Here we can see more clearly than before how the system has reached instability when K_i is 0.8. A higher gain is used which leads to a faster response that causes many more oscillations that increase overtime and do not stop. It has exceeded the critical value.

Variation in frequency in Area A when Load disturbance = -0.05 p.u. and Ki = 0.8

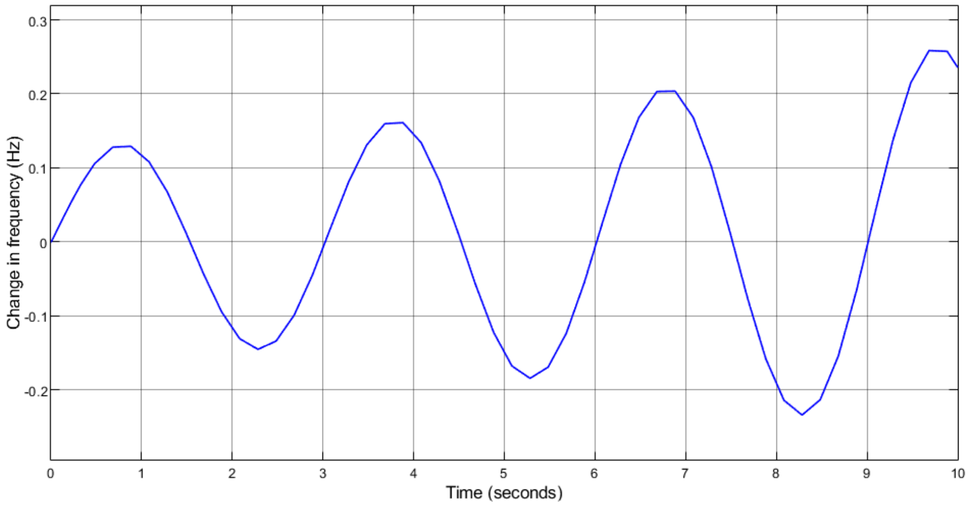

Figure 14: Effect of integral control, Ki = 0.8

When integral action is added and increased, there will be:

- A faster response in the system,
- And more oscillations are occurring causing instability in the system.

3.4 [D] Time (Clock) Error

The time (clock) error is calculated resulting in a system from a step change in demand of -0.05 p.u. The value of integral gain, K_i used is 0.2. The Simulink model developed previously is used but this time an integrator is added to the model.

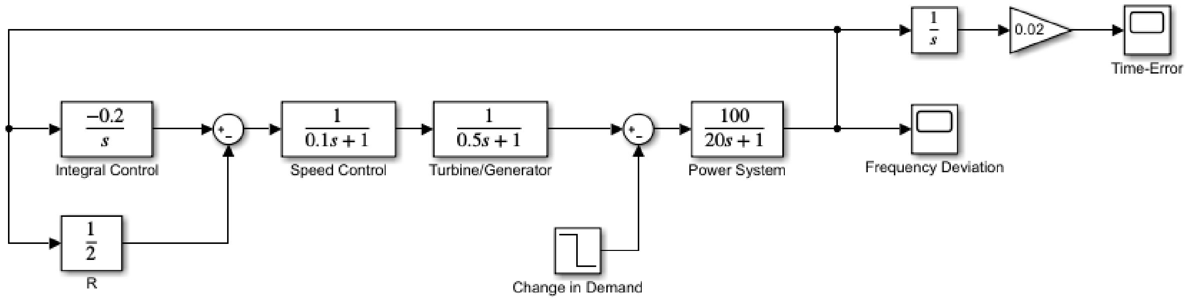

Figure 15: Time Error block diagram

$$\text{time (clock) error} = -\frac{\mathrm{M}}{\mathrm{f_o\ x\ K_i}} = -\frac{0.05}{50\ \mathrm{x}\ 0.2} = 5\ \mathrm{ms}$$

As you can see from the equation above the time error is 5 ms and looking below at the time error graph the time error is around 5 ms when it settles.

Time (Clock) Error

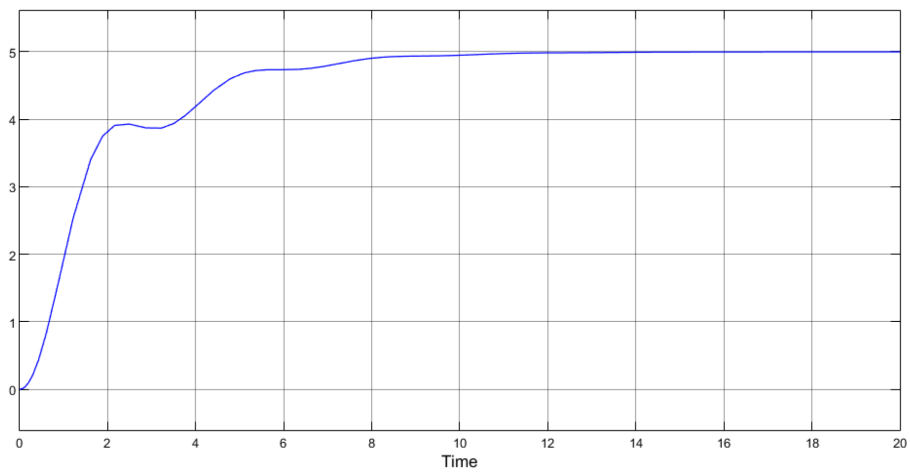

Figure 16: Time (Clock) Error

3.5 [E] TWO-AREA SYSTEM WITH THE INTERCONNECTOR IN PLACE

The Simulink model is developed in Figure 17 below to represent the two-area system for area A and B with the interconnector in place but without ACE Control.

Where,

$$a_{12} = -\frac{\text{Power Base Area 1}}{\text{Power Base Area 2}} = -\frac{1000}{1000} = -1$$

T_{12}^{0} is called the synchronising coefficient and is determined by the operating point.

```
x = 2*pi*(0.05*cos(-1)); % 0.1697
```

Interconnected systems provide support for each other in the event of a sudden application of a large load or fault condition. With these systems there is more economic operations.

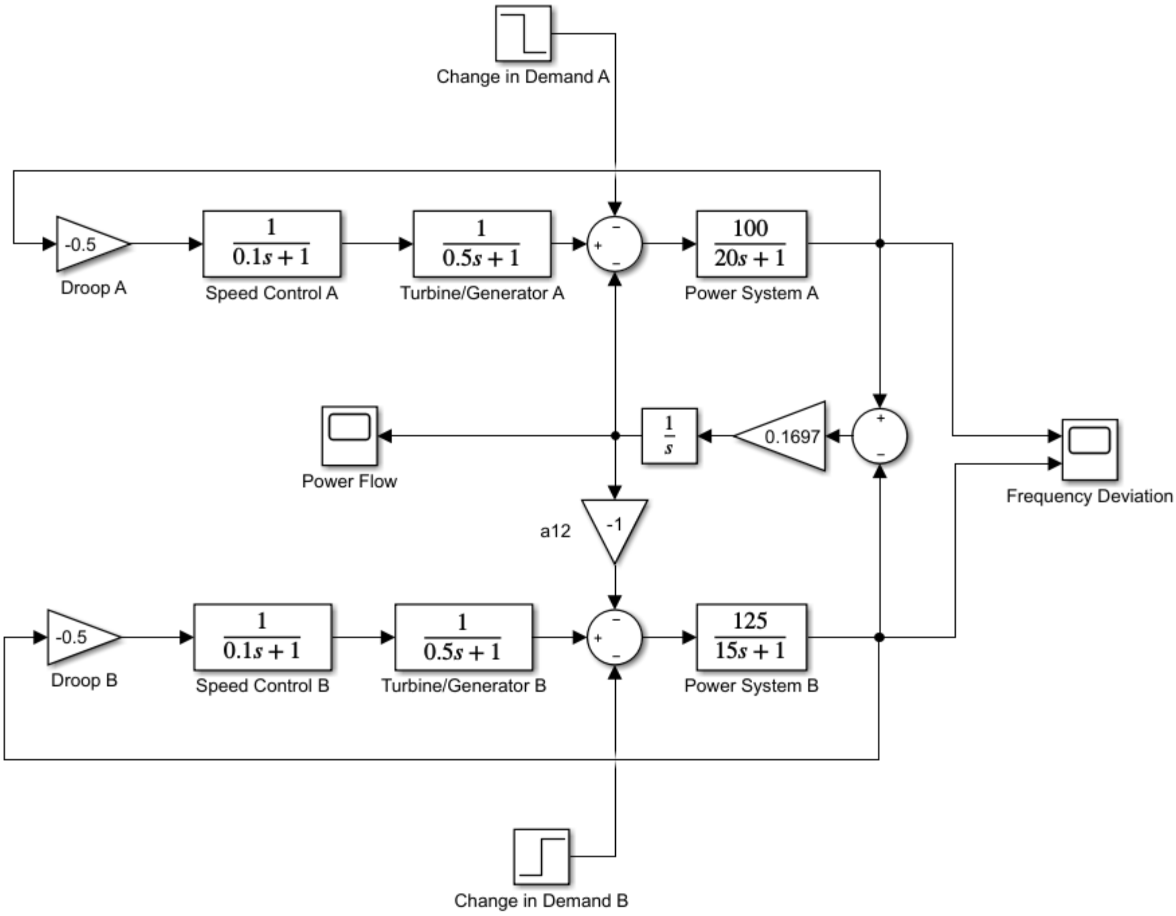

Figure 17: Block diagram representation of a two-area system

The response in area frequency and power flow between the two areas for a step change in area A of -0.05 p.u. and +0.03 p.u. in area B are plotted below.

3.5.1 Response in area frequency

The response in area frequency between the two areas for a step change in area A of -0.05 p.u. and +0.03 p.u. in area B is plotted below in Figure 18. From looking at the plot it is clear that there is a finite frequency error, that is the same for area A and area B. The change in frequency can be returned to zero by using integral action.

Response in area frequency with interconnection

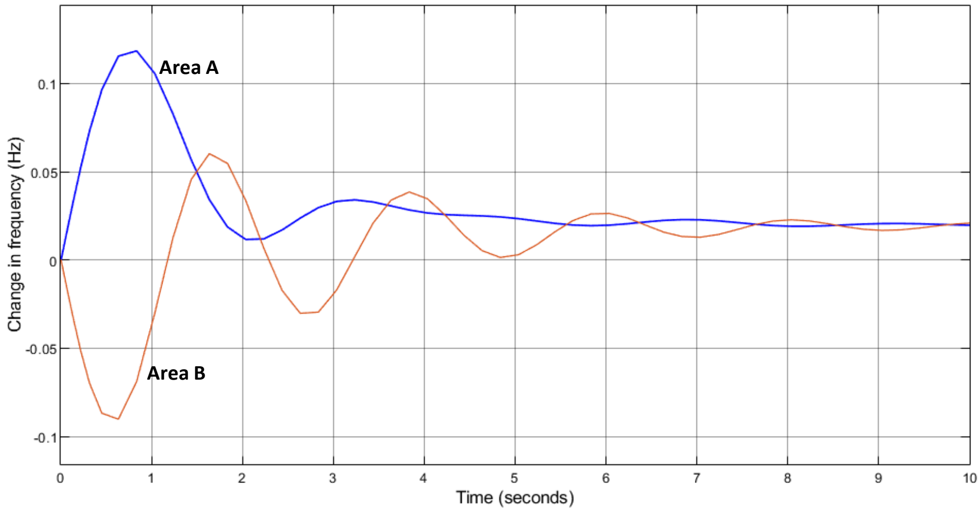

Figure 18: Response in area frequency with interconnection

3.5.2 Response in power flow

The response in power flow between the two areas for a step change in area A of -0.05 p.u. and +0.03 p.u. in area B is plotted below in Figure 19. From looking at the plot it is clear that there is an unscheduled power flow between area A and area B. The power flow can be returned to zero by using integral action like with the change in frequency.

Response in power flow with interconnection

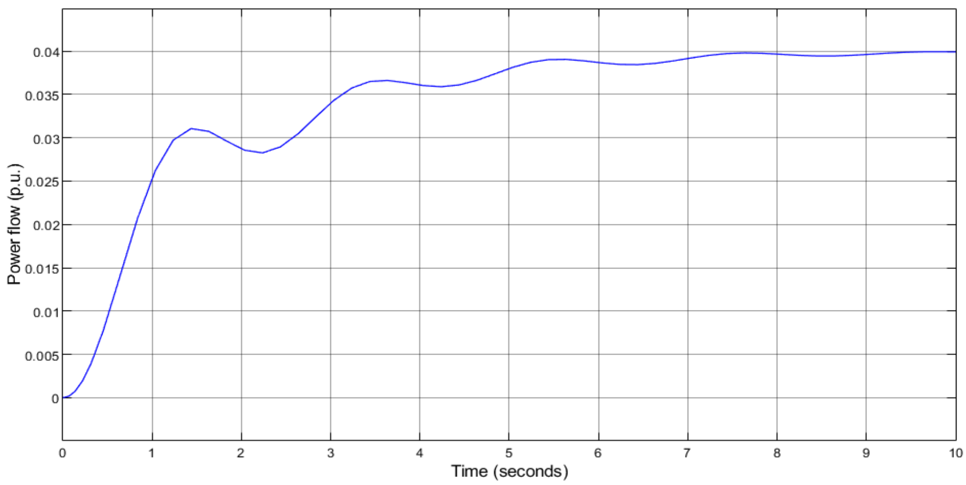

Figure 19: Response in power flow with interconnection

3.6 [F] ADD ACE CONTROL TO THE SYSTEM

The Simulink model is developed in Figure 20 below to represent the two-area system for area A and B with the interconnector in place and the ACE Control added. The ACE control is added to ensure that the power flow and the frequency between the areas return to their pre-disturbance values. The values B (frequency bias parameter) and, K_i (integral control) are used to control how quickly the frequency and power are driven to zero after disturbance. There is a step change in area A of -0.05 p.u. and +0.03 p.u. in area B.

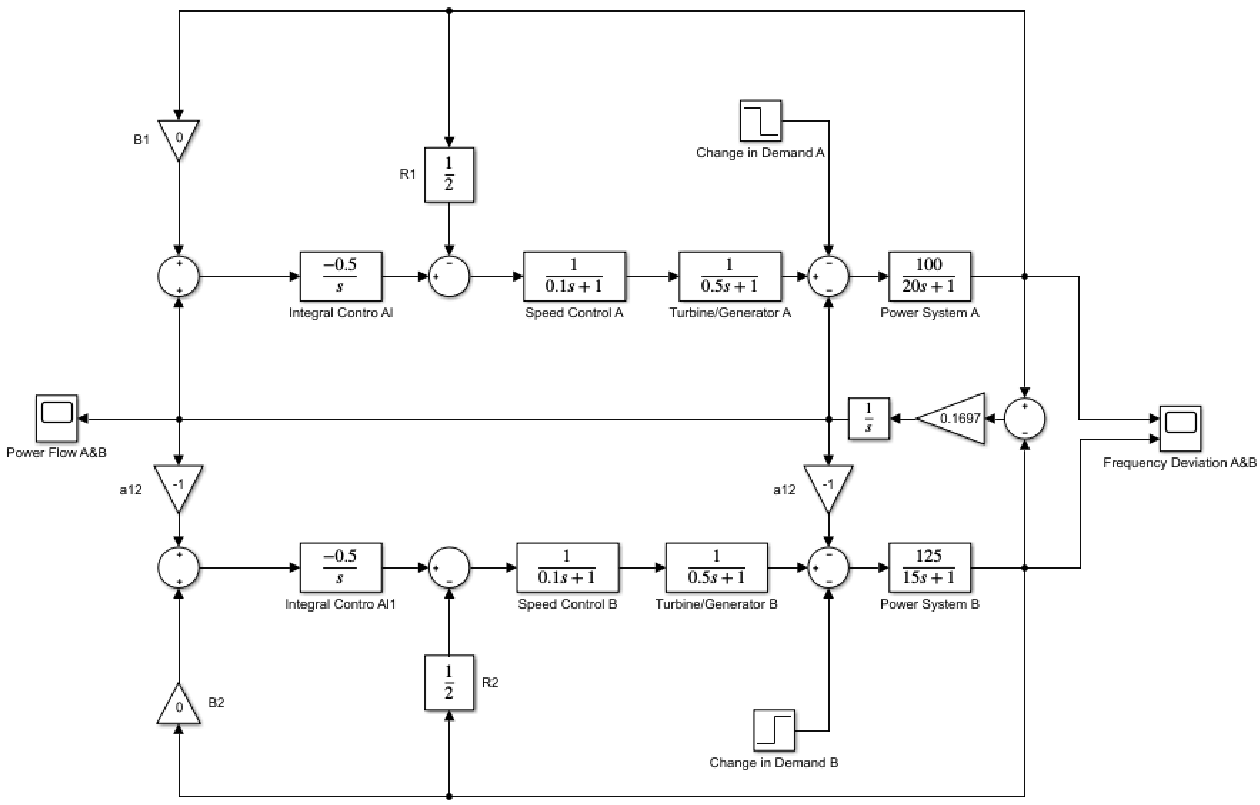

Figure 20: Block diagram representation of a two-area system with ACE control

3.6.1 High values of Ki = 0.5 and low values of B = 0

The frequency and power flow between the areas A and B is show in Figure 21 below where the integral control, K_i = 0.5 for both areas and the frequency bias parameter, B = 0 for both areas. Here the power flow returns to zero, but a sustained frequency error is present. There is power integral control only.

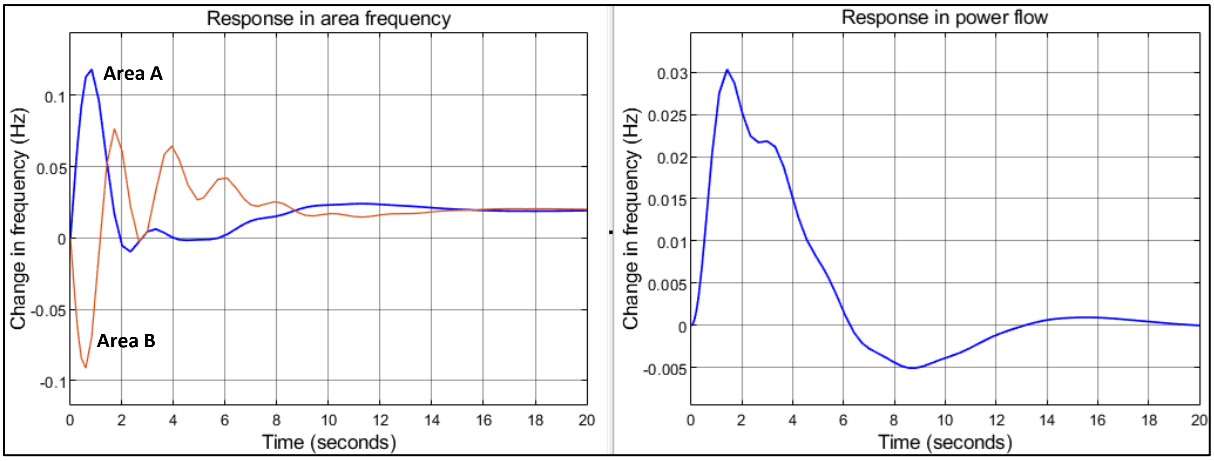

Figure 21: Power integral control only

3.6.2 Low Values of Ki = 0 and high values of B = 40

The frequency and power flow between the areas A and B is show in Figure 22 below where the integral control, K_i = 0.01 for both areas and the frequency bias parameter, B = 50 for both areas. Here the power flow is very slow in returning to zero even though the frequency error rapidly dies away. There is frequency integral control only.

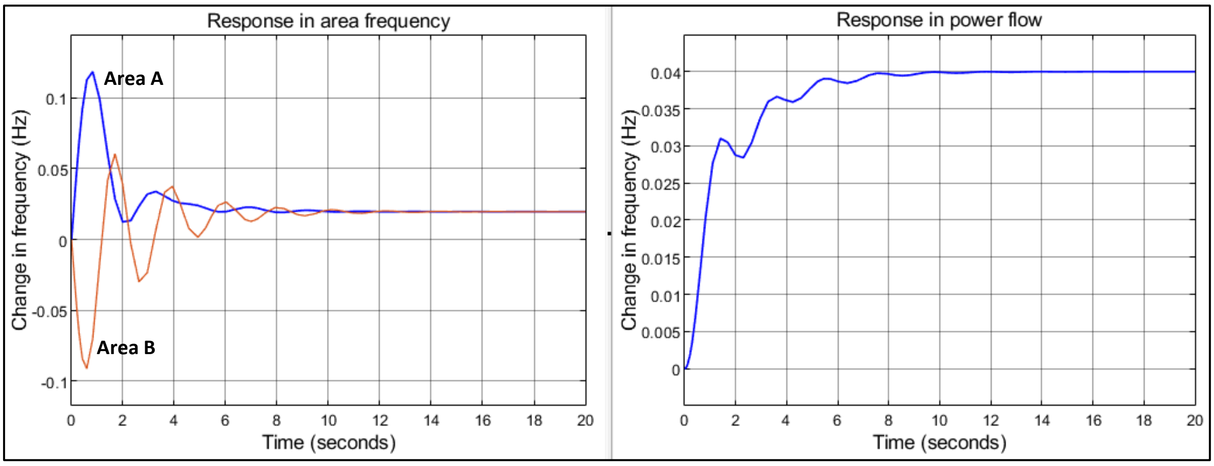

Figure 22: Frequency integral control only

3.6.3 Reasonable response when Ki = 0.3 & B = 20

In this section appropriate values for the integral control, K_i and the frequency bias parameter, B are selected to obtain reasonable frequency and power flow responses for area A and area B. The responses can be seen below in Figure 23, where K_i = 0.3 and B = 0.5. There is a combined frequency and power control involved and it is clear the power flow returns to zero rapidly and the frequency error rapidly dies away.

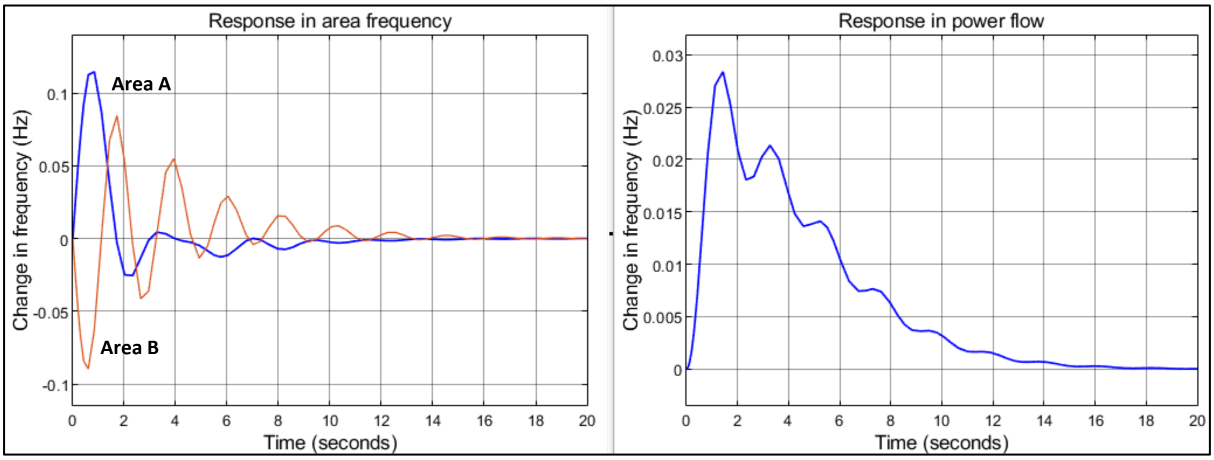

Figure 23: Combined frequency and power integral control

3.7 [G] VALUES FOR THE PARAMETERS FOR A POWER FREQUENCY CONTROL MODEL

The parameters discussed are identified in a system representing two power system areas connected by a transmission line. The two control areas are represented by a thermal power plant and a hydro power plant. The typical parameter values are as follows;

Parameter	Area A	Area B
T_p / K_p	0.2	0.12
D = 1/K_p	0.01	0.008
T_G	0.5	0.5
T_T	0.1	0.1
R	4% = 2.0 Hz/p.u. MW	4% = 2.0 Hz/p.u. MW
K_i	0.2	0.1

Table 2: Parameter values

Where K_p is the power system gain, T_p is the power system time constant, TG is the thermal governor time constant, T_T is the turbine time constant, R is the speed droop due to governor action and Ki is the integral gain.

Parameter R is set as a parameter of both, thermal and hydro governors within SPS-model. Therefore, it needs not to be identified. Parameter R from SPS-model must be multiplied with the nominal frequency fn = 50 Hz to obtain its value for LIN-model.

Parameter T_T is valid only for thermal power plants. It can be identified from the response of steam turbine's output power to a step change in governor's gate opening. Differences between turbines used in area A and area B are in time constants and torque fractions of high, intermediate and low pressure sections.

Parameter TG is valid only for thermal power plants. With nonlinearities neglected, it can be approximated with servo motor time constant, Tsm, which is set as a parameter of thermal governor subsystem in SPS-model. Both thermal power plants have identical governors.

To identify parameters K_p andT_p, an alternative form of a transfer function describing power system dynamics is used:

$$\frac{\Delta f}{\Delta P_{\Sigma}} = \frac{\Delta f}{\Delta P_g - \Delta P_{tie} - \Delta P_d} = \frac{1}{D + Ms}$$

Where D is area's damping coefficient and M is area's inertia constant. Damping coefficient is identified
from isolated control area frequency response to step changes in generation and consumption. D = Dident/ f n. Since there is only one synchronous machine per control area, area's inertia constant can be computed as M = 2H/ fn , where H is machine's coefficient of inertia, which is a set parameter of SPS model. Parameters K_p and T_p can be computed from parameters M and D as:
$K_p = \frac{1}{D}$, $T_p = \frac{M}{D}$

The integral gain Ki is obtained as a set value of the control output which is generated due to accumulated frequency error in the power system.

CONCLUSION

From the study of the parameters presented above, it is clear that the values of each parameter can be determined in practice via calculation with specific formulas and also can be found through SPS model implementation. SMC-based algorithm would show a good behaviour with both linear and nonlinear models.

In the electric system, the balance between power generation and the load must be guaranteed all the time, if not met serious consequences such as blackout may occur. The balance between generation and load is met by controlling the frequency of the system.

The system frequency stability is one of three criteria which must be met all the time to keep the system stable.

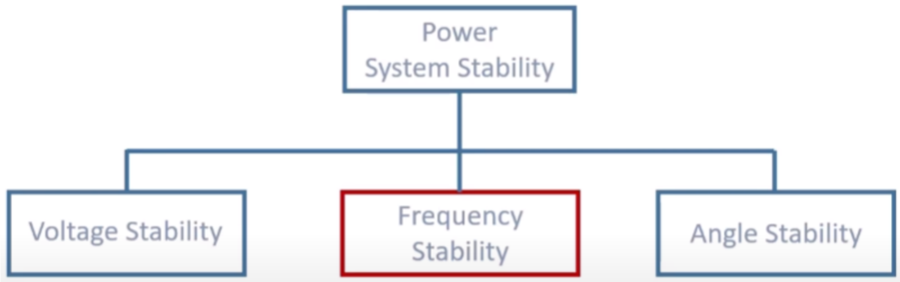

Figure 24: Power system stability [6]

If the load exceeds the power supplied by the generation, therefore frequency will be slowed down and vice versa.

Frequency control

When after a change of the load or a loss of generation there are three consecutive phases which are:

- **Phase1: Inertia is immediate**

  In this phase demand is met by using stored energy in the rotating mask the generation involved or if generation exceeds the load the energy produced is stored in the rotating masses meaning the rotating speed is accelerating, and frequency goes up.

- **Phase 2: Local automatic for each generator (Droop)**

In the second phase there is a very local generation control known as the droop, which is the opening or closing the values for the steam engineer or for example Hydropower plants.

During the experiment, observed that the frequency remains relatively close to the nominal even with the change in the load. When adjusting the frequency or droop is applied then we observe less stress on the response.

- **Phase 3: Secondary semi-automatic**

  In the third phase, there is a regional control system which controls the drop settings of the generators and with regional controls the region can fully meet the nominal frequency.

- **Phase 4: Manual dispatch of additional generation**

  In fourth generation which may have the additional generation which requires a setup and connected/disconnected to the grid.

4 ADDITIONAL ELEMENT - TIME ERROR

4.1 TIME ERROR IN MODERN POWER SYSTEMS

Time error is the difference between standard time and the time based on the system frequency. Power system frequency deviation away from its official value results in electric clocks running fast or running slow knowing as the Time error, where electric clocks use power system frequency as their timing reference. The oscillations of power grid frequency cause a time error of a few seconds during the period of one day. As time goes by, this error gradually accumulates and finally tends to cause a large time drift of synchronous electric clocks in the long term [3].

Now adays, most of the modern systems clocks no longer rely on the power systems frequency for accurate time keeping. Limiting accumulated time error was once important for accurate time keeping. In the past synchronous clocks that rely on the power system frequency for time keeping were commonplace. Removing this may help to reduce the cost of managing the power system and support better system operation [5].

Change in frequency (even transient) causes time errors and clocks are controlled by the frequency given by

$$t_e = \frac{1}{f^0} \int_0^T \Delta f dt$$

If the accumulative time error ΔT is forced to be zero, the following equation can be derived and accumulative time error being zero is that the long-term average frequency should be equal to the official frequency.

$$\bar{f} = \frac{1}{T} \sum_{t=1}^{T} f_t = f^*$$

Where $\bar{f}$ is the long-term average of system frequency and f^* is the official frequency.

As in many countries 50Hz to 60 Hz range of frequency is used as average frequency to operate a power system When the power system operates at a frequency less than 60Hz there occurs a delay or slow accumulated time error, meaning that the system is working slower than the other interconnected system. When the error persists for more time, the power system may get shut down and the system gets out of synchronization.

Statistical analysis on time error of electric clocks around the world is presented in Table 2. The time error correction (TEC) process provided by electric utilities is analysed and the worldwide TEC practice is investigated. Eventually, regions of the world where electric utilities provide TEC service are differentiated from those without TEC services as shown in the Figure 24 [4].

Location	Maximum Time Error (Run Fast, Seconds)	Minimum Time Error (Run Slow, Seconds)	Average Time Error (Seconds)
USA, Seattle	+11.14	−09.58	+00.16
USA, Matton	+18.38	−08.05	+00.78
Sweden, Stockholm	+20.52	−12.11	+02.97
USA, San Angelo	+07.15	−05.68	+00.58
Brazil, Itajubá	+80.39	−00.00	+43.02
Japan, Karuizawa	+07.59	−06.75	+00.04
UK, Sheffield	+16.72	−16.10	+03.34
Denmark, Aalborg	+17.88	−10.81	+01.07
China, Shanghai	+333.94	−00.00	+180.70
Australia, Brisbane	+04.43	−05.16	+00.08
India, Kanpur	+00.00	−144.76	−69.83
Latvia, Riga	+02.17	−35.85	−17.37

Table 3 - Statistical Analysis of the monthly time error around the world [3-4]

In Figure 24, shows that the countries providing TEC services are concentrated in North America and Europe. In Asia and South America, most countries do not provide TEC services. Therefore, synchronous electric clocks installed in these countries usually tend to have a large time drift in the long term.

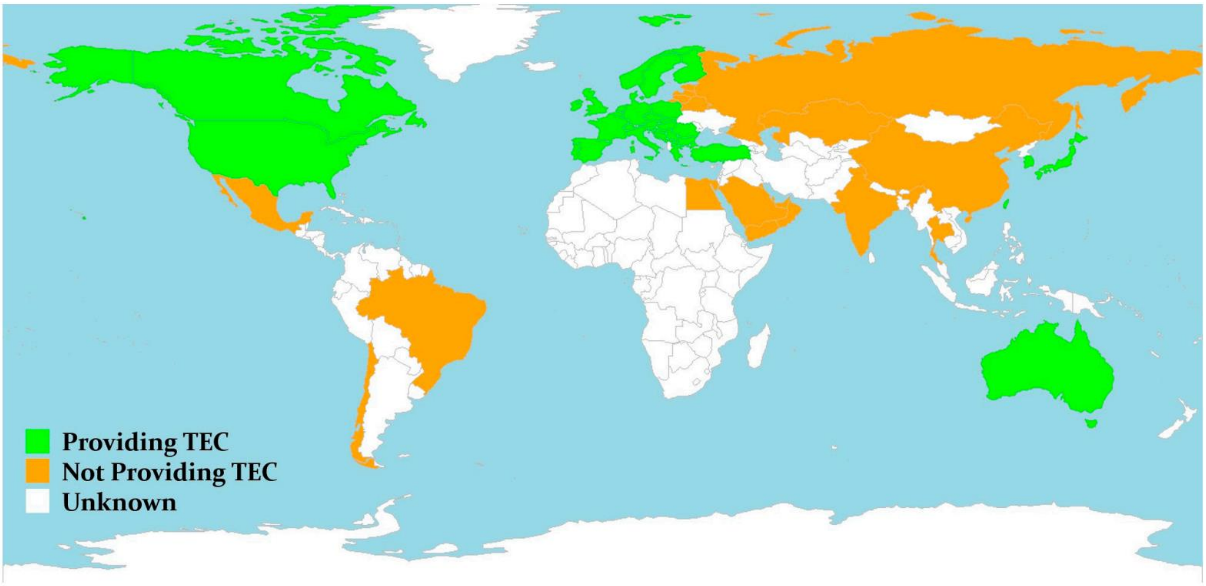

Figure 25: Time error correction (TEC) is practised around the world. The green region indicates the countries providing TEC service. The orange region indicates the countries not providing TEC [3-4]

4.2 LIMITATIONS ON TIME ERRORS

According to the Grid Code, the frequency operating requires that the Time error shall not in normal circumstances exceed ± 10 seconds and the frequency target is set to 49.95 or 50.05 Hz to correct time error [1]. However, when the frequency changes, the time changes too. That is what has been happening in Europe.

EirGrid and SONI undertake the following process to correct the electrical time error deviation [2].

- EirGrid, in its role as SA monitor, agrees that the target frequency will be reset with SONI and agree to an effective time of at least 15 minutes in the future [2].
- Use an EDIL message to inform all generators of the new frequency setpoint and the time from which it becomes effective [2].
- Reset the target frequency settings in the EMS [2].
- Record timing and frequency settings in the NCC log [2].
- To revert to 50.00 Hz, once agreed with SONI, NCC cancel the instruction from the EDIL Issued Instruction list and re-enter 50.000 Hz in EMS [2].

To make sense of this, the clocks in devices use the frequency of electricity to keep time. Electric power is a form of an alternating current (AC), where the direction of the flow of electricity (current) oscillates 50 times a second in Europe and 60 times a second in America.

The power system should operate within the frequency ranges as shown in Table 4.

Description	Range
Normal operating range[6]	49.8 to 50.2 Hz
During **Transmission System** disturbances	48.2 to 52.0 Hz
During exceptional **Transmission System** disturbances, not exceeding 60 minutes duration for frequency in the range 47.5 to 49.8 Hz and 50.2 to 52.0 Hz and not exceeding 20 seconds for frequency in the range 47.0 Hz to 47.5 Hz.	47.0 to 52.0 Hz
Maximum rate of change of frequency	0.5 Hz per second

Table 4 - System Frequency Ranges [1]

The electricity transmission system operators (TSO) may implement measures to ensure the frequency ranges are respected by providing additional reserve during the mix of sources of power in-feeds varies and system response/inertia is therefore varied.

According to [3] In addition to the three interconnection systems in North America discussed above, the time error of the synchronous clock using power grid frequency in worldwide power grids are also analyzed in this subsection. The study shows some important statistics of the monthly time error around the world. It can be observed that the time error is usually less than ±30.00 s in most countries. Moreover, power grid frequency, as a timing source with almost zero-cost, stable performance and high accuracy, is generally accessible and available anywhere, anytime as long as there are power transmission lines in service.
Another interesting observation is that the average time error is positive for most countries except for India and Latvia, meaning that the synchronous clock is more likely to run fast. This also indicates that

the long-term power grid frequency is slightly higher than its nominal value. We also find some countries with the time error larger than one minute, such as Brazil and China.

4.3 IMPLICATIONS OF THE TIME ERROR

Time errors in power systems affect the small signal stability of power systems. The power system itself becomes unable to restore normal voltages even under small perturbations in the power system.

Large frequency deviations are much more likely to occur during those times when scheduled frequency is offset by a Time Error Correction than when Time Error Correction is not performed.

As we know that Interconnected power system has many advantages like Economical operation, Increase the reliability of power supply, Exchange of peak load, etc. However, it also comes with many limitations, as all the systems should operate at the same frequency. Frequency control method is used in interconnected power system during AGC operation.

Operation is divided into different grades based on its frequency deviation value. If the system frequency bias is set too low, then the adjacent system will respond to the trouble more than its share of bias response.

5 DISCUSSIONS AND CONCLUSIONS

To conclude, when a single control area A was developed and injected with a load disturbance of -0.05 p.u. the change in frequency dropped rapidly and it was above zero and when a single control area B was developed and injected with a load disturbance of +0.03 p.u. the change in frequency also dropped rapidly but it was below zero.

When power frequency control (integral control), K_i of a value of 0.2 was added to the single control area A with a load disturbance of -0.05 p.u. the variation in frequency had a small number of oscillations, and these oscillations decreased with time, and therefore it was in a stable condition. When the integral control, K_i was increased to 0.7 more oscillations were present with a faster repose as it had exceeded the critical value and it caused instability. Therefore, when integral action is added and increased, there is a faster response in the system and more oscillations are occurring causing instability.

To get the time error an integrator was added to the model and was divided by 50, so it could be read on the plot. The time error was about 0.5 ms when read from the plot and when calculated.

For a two-area control system with the interconnector in place the response in area frequency between the two areas for a step change in area A of -0.05 p.u. and +0.03 p.u. area B, showed that there was a finite frequency error, that was the same for area A and B and the change in frequency could be returned to zero by using integral action. The response in power flow showed that there was an unscheduled power flow between area A and B and the power flow could be returned to zero by using integral action like with the change in frequency. The interconnected systems are very beneficial as they provide support for each other in the event of a sudden application of a large load or fault condition.

Lastly, ACE control was added to the two-area control system. The ACE control is added to ensure that the power flow and the frequency between the areas return to their pre-disturbance values. When there was a high value for K_i (0.5) and a low value for B (0) for both areas the power flow returned to zero, but a sustained frequency error was present. When there was a low value for K_i (0) and a high value for B (40) for both areas the power flow was very slow in returning to zero even though the frequency error rapidly died away. Finally, appropriate values were obtained, where K_i = 0.3 and B = 0.5 and using these values the power flow returned to zero rapidly and the frequency error rapidly died away and they both returned to their pre-disturbance values.

6 REFERENCES

[1] "Operating Security Standards", Eirgridgroup.com, 2022. [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/Operating-Security-Standards-December-2011.pdf. [Accessed: 26- Feb- 2022]

[2] "Synchronous Area Operational Agreement for Synchronous Area IE/NI", Eirgridgroup.com, 2022. [Online]. Available: http://www.eirgridgroup.com/site-files/library/EirGrid/Synchronous-Area-Operational-Area-for-the-Ireland-and-Northern-Ireland-S....pdf. [Accessed: 27- Feb- 2022]

[3] "Impacts of Power Grid Frequency Deviation on Time Error of Synchronous Electric Clock and Worldwide Power System Practices on Time Error Correction", Mdpi.com, 2022. [Online]. Available: https://www.mdpi.com/1996-1073/10/9/1283/pdf. [Accessed: 27- Feb- 2022]

[4] "https://curent.utk.edu/2017SiteVisit/Zhang_Yao_UTK_Liu_1.pdf", Curent.utk.edu, 2022. [Online]. Available: https://curent.utk.edu/2017SiteVisit/Zhang_Yao_UTK_Liu_1.pdf. [Accessed: 27- Feb- 2022]

[5] "FACT SHEET: REMOVAL OF LIMIT ON ACCUMULATED TIME ERROR", Aemc.gov.au, 2022. [Online]. Available: https://www.aemc.gov.au/sites/default/files/2018-12/Fact%20Sheet%20-%20Accumulated%20time%20error_0.pdf. [Accessed: 27- Feb- 2022]

[6] G. Schett, "online electric circuit simulator", Ecsp.ch, 2022. [Online]. Available: https://www.ecsp.ch/. [Accessed: 27- Feb- 2022]