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Dynamic stability analysis of microgrid by integrating transfer function of DERs

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Abstract
A microgrid is an integrated form of distributed energy resources (DERs) which are connected together to serve electrical power to the selected consumers or can exchange power with the existing utility grid suitably under standalone or grid connected mode. The microgrid can be cited as a physical system which is a combination of DERs such as, Photovoltaic Generator, Wind turbine, Fuel Cell, Microturbine etc. and can be modelled with suitable assumptions depending upon specific operational condition to be studied. Interconnection of several kinds of power sources would impact the quality of power within the microgrid. Since voltage and frequency are not the only factors for a system delivering good quality power, the capacity of the same to withstand instability due to transient condition is one of the prime factors to be considered to accept a system as a stable system. Before practical integration of distributed energy resources, it would be essential to check the stability of the system at the design stage. In this paper, the authors have presented the microgrid based on control system engineering. To represent the individual components of microgrid, the DERs (Distributed Energy Resources) have been represented with their transfer functions and they have been simulated using Simulink-Matlab. To observe the response of the DERs, the frequency fluctuation due to step and random change in output power/load are considered as the main factors for stability analysis. All the DERs are integrated forming the microgrid which is represented with an equivalent transfer function based model. The models are studied and results are discussed with the waveforms. This paper shows one feasible method to check the dynamic stability of a proposed microgrid.

Keywords: Dynamic stability of microgrid, Integration of DERs, Microgrid, Pole-Zero plots, Polynomial stability test.

1. Introduction

The stability of a microgrid, which is interconnection of several distributed energy resources, is its ability to return to normal or stable operation after having been subjected to some form of disturbance. Conversely, instability means a condition denoting loss of synchronism or falling out of step. Stability considerations have been recognized as an essential feature of microgrid planning. For proper working of microgrid, the stability problems are to be taken care, covering the steady state, dynamic and transient condition. The study of steady state stability mainly concerned with the calculation of maximum limit for the DER loading before losing synchronism, provided the loading is increased gradually [1]. In microgrid, dynamic instability is more probable than steady state instability. The dynamic instability may occur due to sudden fluctuation of load and the system oscillation may occur which has to die out completely within a short time. If the oscillation of the system output persists for a long time, then the microgrid will be dynamically instable, which may be a serious threat to the interconnection of DERs. This paper shows a feasible method to study the dynamic stability of a microgrid. Initially, the individual DERs are presented with their first order transfer functions based on assumption on the linearity of the systems with reference from the study of Battery Energy Storage (BES) facility system [2, 3].

2. Response of distributed energy resources against frequency and power fluctuation

This paper discusses the dynamic stability of micro-grid operation and presents the control scheme of combining fuel cell system and micro-turbine as a hybrid system to enumerate the micro-grid system's ability to solve power quality issues resulting from frequency fluctuations due to sudden and random load fluctuation [4]. With reference to [3], large Battery Energy Storage (BES) facility may provide significant dynamic operation benefits for electric utilities. One area in which a BES facility could be useful is the frequency regulation requirement. This feature is significantly important in island power systems. In [3], D. Kottick, M. Blau and D. Edelstein quantified the effects of a 30 MW battery on frequency regulation in the Israeli isolated power system. The study was performed on a single area model representing the whole power system and containing a first order transfer function that represented the BES performance. In reference to [2] and [3], in this paper, each source is presented with their first order transfer functions. Next section focuses on the stability of each system against fast frequency fluctuation and sudden output power unbalance. Each system is observed with their output waveforms showing overshooting due to sudden power fluctuation and finally reaching steady state condition.

2.1 Fuel cells

With reference to [5], in order to introduce and apply small fuel cell cogeneration to a building, it is necessary to investigate the response characteristics of the power and heat power with load fluctuations. In particular, the power demand pattern of an individual house is a load that has usually gone up and down rapidly for a short time. If a system is controlled to follow such a load, the difference in the response and load increases. As a result, the power quality (voltage and frequency) of this power system may worsen. “Fluctuation in a short period, such as an inrush current” and “fluctuation in a long period to cause in change of demand” are included in the power load. “Change over a long period” means a step change in the power demand. With the change factor of the transient power demand, such as with an inrush current, there is a change over a long period in the demand. When “transient power demand” is defined as load fluctuation and “change over a long period” is defined as demand fluctuation, the power load changes of an individual house have large fluctuations of both. If the transient response of a single cell of a fuel cell is examined, it seems that stable response characteristics are acquired for the load fluctuation characteristics of the household appliance items used in common homes [5]. As referred in [2], the sudden real power fluctuation of a fuel cell generator can be represented by its transfer function as stated in equation (1).

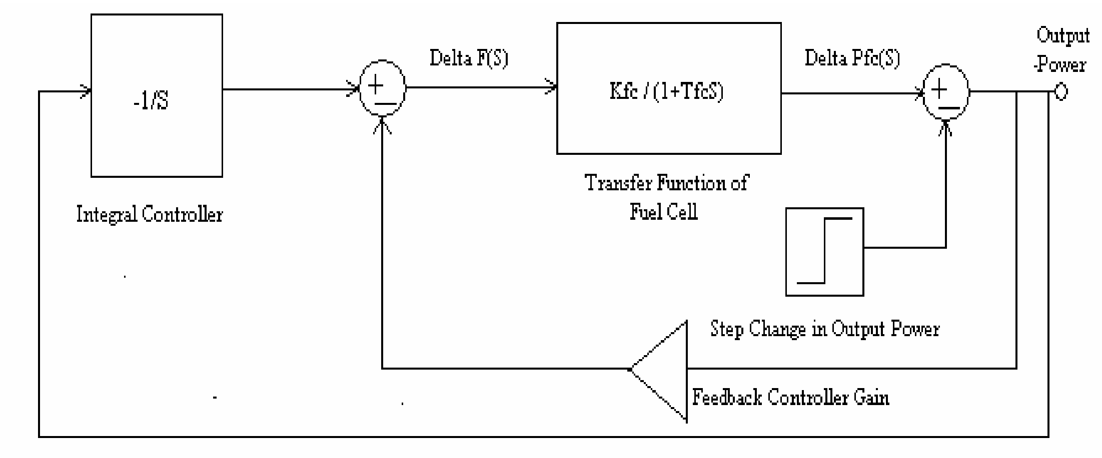
$$\Delta P_{FC}=[K_{FC}/(1+T_{FC}S)]\Delta f \tag{1}$$

where, ΔP_{FC} = Real time power fluctuation, Δf = Frequency fluctuation due to sudden fluctuation of real power, P_{FC} = Output power of fuel cell, K_{FC} = Gain of fuel cell, T_{FC} = Time Constant of fuel cell.

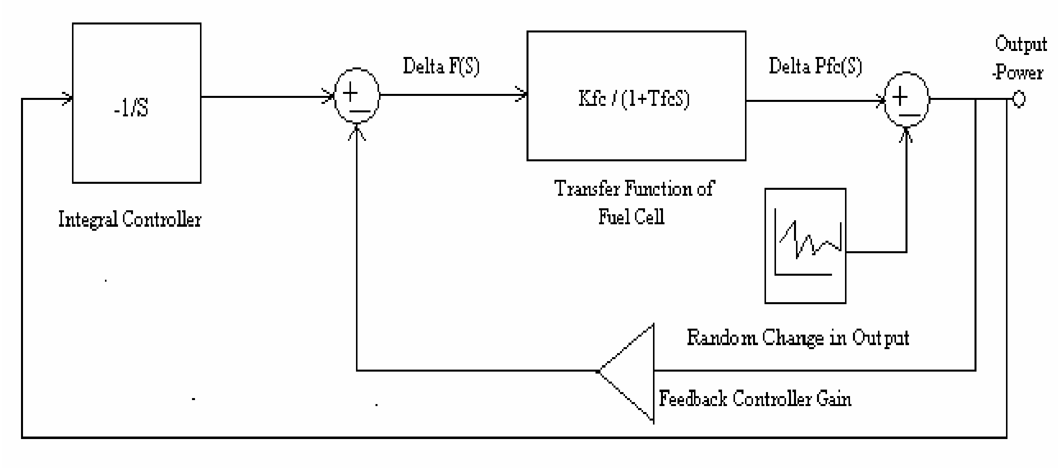
In Figure 1, the fuel cell is presented with the Proportional plus Integral control scheme where the sudden fluctuation of output power is simulated with a step and random change of output respectively. Due to this step change in output power, the fluctuation of frequency is shown in Figure 2.
Sudden fluctuation of frequency due to that disturbance in output is shown with overshooting and damping and finally reaching steady state. The variation of output power and system response due to random variation of output power is shown in Figures 3 and 4 respectively.

2.2 Microturbine

As referred in [6], it is well known that the power output of microturbine can be controlled to compensate for load change and alleviate the system frequency fluctuations. Nevertheless, the microturbine may not adequately compensate rapid load change due to its slow dynamic response. Moreover, when the intermittent power generations from wind power and photovoltaic are integrated into the system, they may cause severe frequency fluctuation [6].



(a)



(b)

Figure 1. Output power versus frequency control of fuel cell: (a) for step change in output , and (b) for random change in output

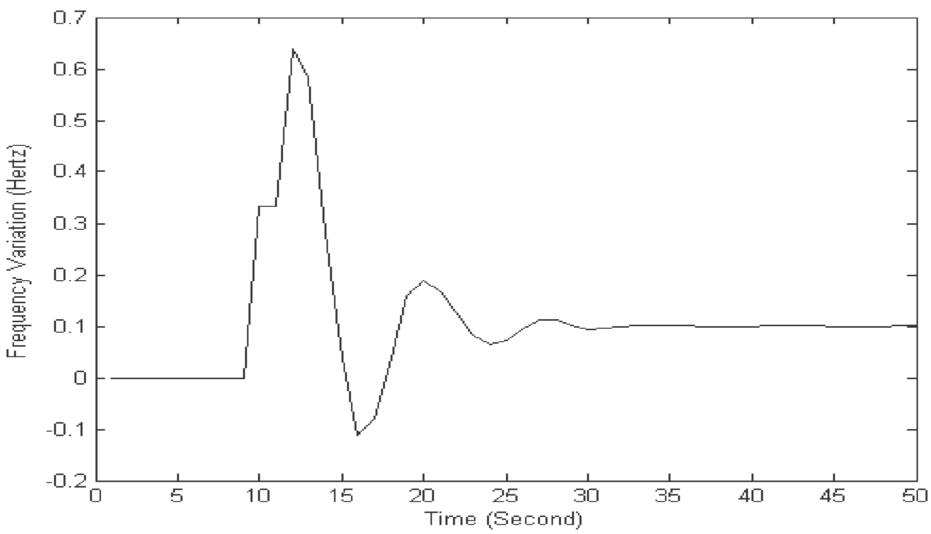


Figure 2. Frequency variation in fuel cell

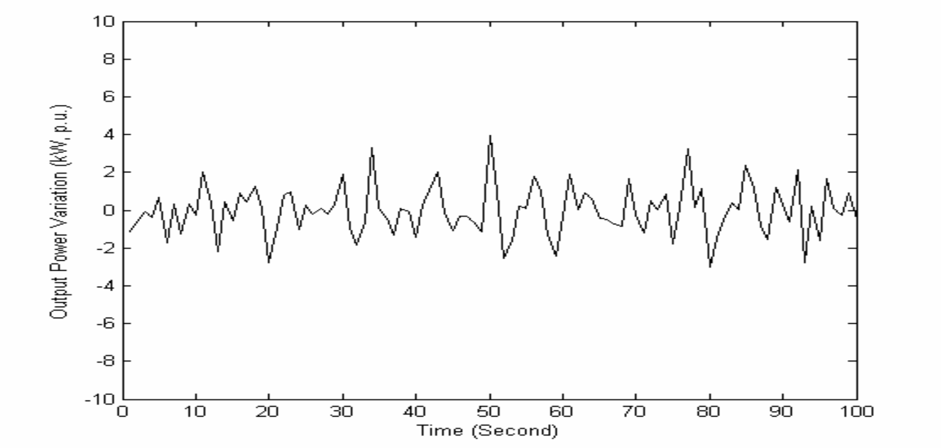


Figure 3. Output power variation in fuel cell

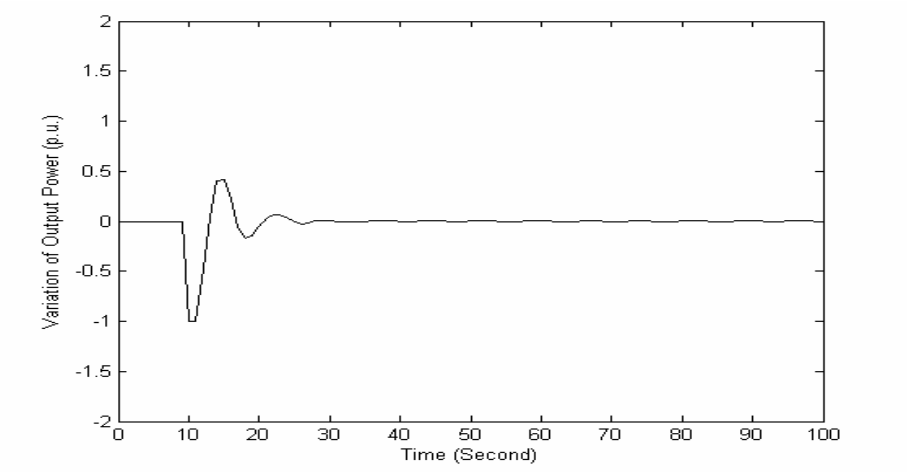


Figure 4. Output power variation for random change in load of fuel cell

In order to study the fast dynamic response, each system is studied separately to observe the absorption of the frequency and power fluctuations. Simulation results exhibit the robustness and stabilizing effects of microturbine.
A Microturbine block which is normally intended for base load supply is shown in the Figure 5.

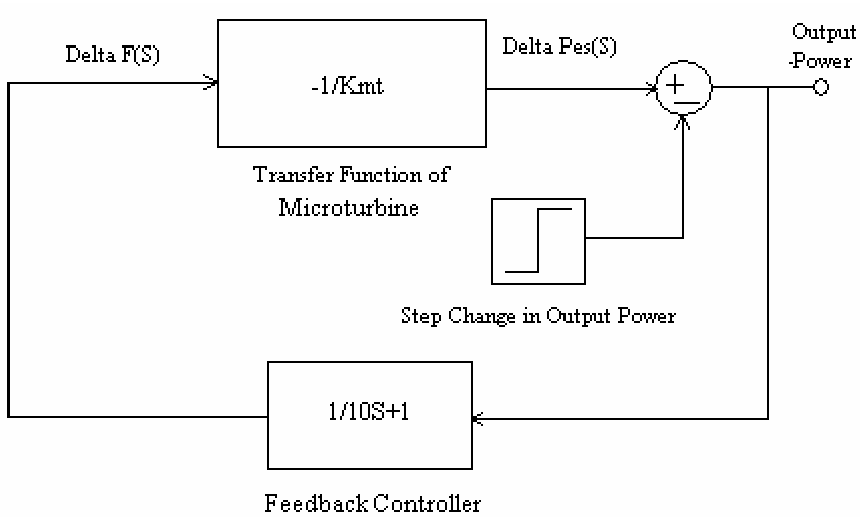


Figure 5. Output power versus frequency control scheme for microturbine

Considering the linear power versus frequency droop characteristic, the transfer function based formulation is shown below [2] in equation (2).

$$\Delta P_{MT}=(-1/K_{MT})\Delta f \tag{2}$$

where, ΔP_{MT} = Real time power fluctuation, Δf = Frequency fluctuation due to sudden fluctuation of real power, K_{MT} = Droop property of Microturbine output.

Variation of output power in Microturbine due to step change and random fluctuation of load is shown in Figures 6 and 7 respectively. The waveform obtained shows zero error after damping off the overshoot.

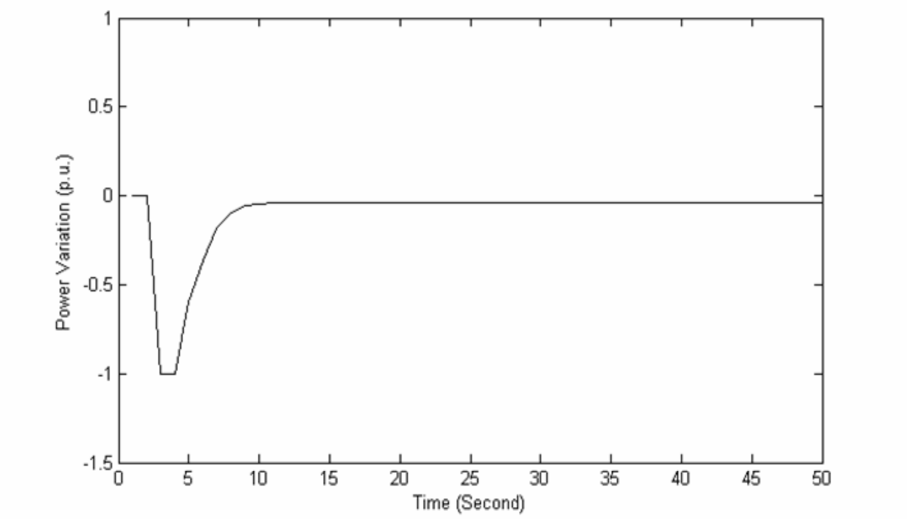


Figure 6. Output power variation in microturbine for step change in load

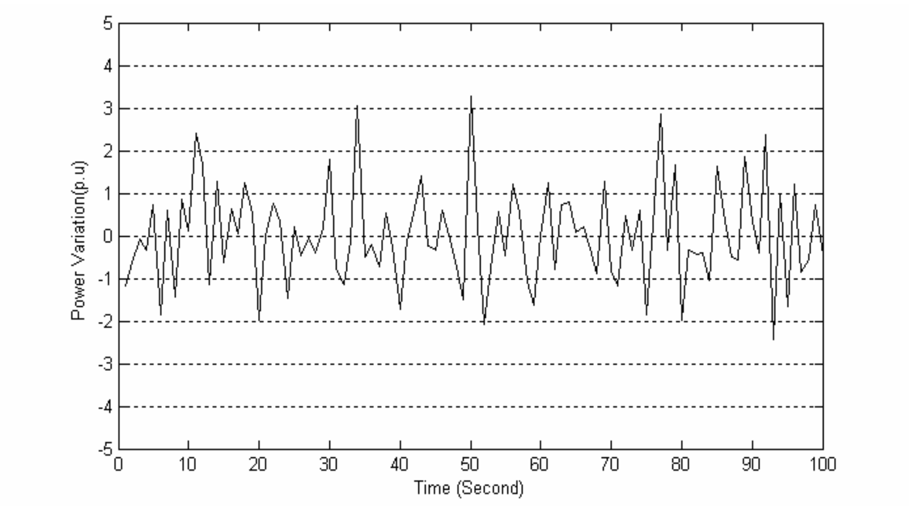


Figure 7. Output power variation in microturbine due to random change in load

3. Transfer function based model of a microgrid: Study of frequency and output power fluctuations

In the previous section, the Fuel Cell system and Microturbine are studied separately and simulated to observe the dynamic instability. In this section, the transfer functions of DERs are integrated as shown in Figure 8 forming microgrid. The integrated system is tested for dynamic instability with a step change in the output power. Proportional plus integral control strategy is used and the output power wave form obtained is shown in the Figure 9 below. The result shows satisfactory performance of the microgrid model against dynamic instability. The model is studied for random load fluctuation and the response is observed as shown in Figure 10. Step response output data are shown in Table 1.

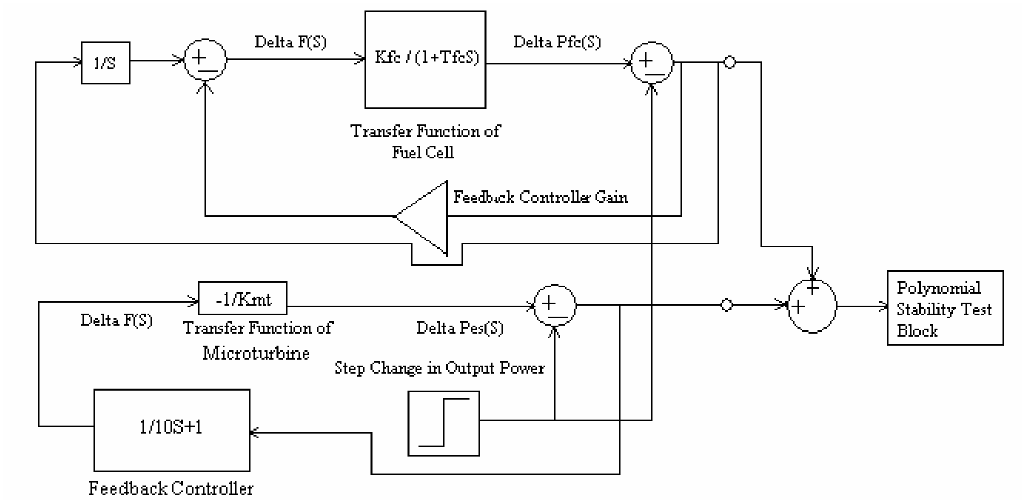


Figure 8. Transfer function based model of microgrid

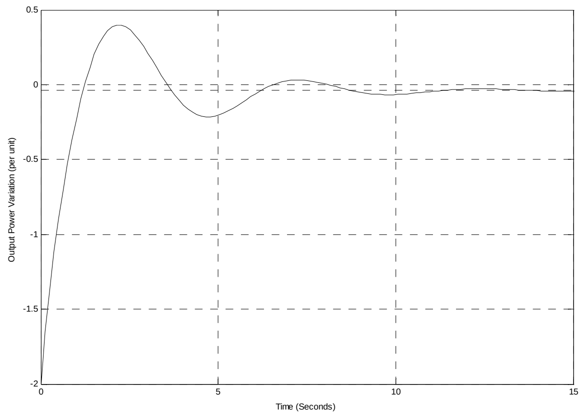


Figure 9. Output power variation in microgrid due to step change in load

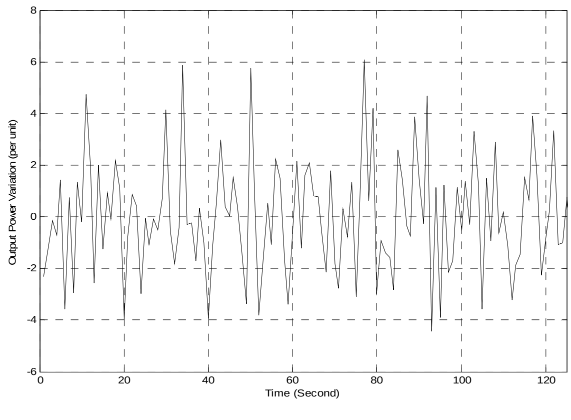


Figure 10. Output power variation in microgrid due to random change in load

Table 1. Step response obtained from linear analysis of fuel cell, microturbine & microgrid

	Fuel Cell	Microturbine	Microgrid
Peak Amplitude	0.887	-25	-2
Overshoot (%)	Infinity at t=0	$2.5*10^3$	$5.1*10^3$
Rise Time (Second)	0	0.845	0.928
Settling Time (Second)	11.7	1.5	8.1
Final Value	0	-0.962	-0.0385

4. Stability analysis of microgrid

The microgrid shown in Figure 8 are studied for stability analysis with Pole-Zero mapping [7] using Matlab-Simulink. The main objective of this section is to check if there is any root of the characteristic equation on the right half of s-plane. The step change in output power is considered as input and the output power variation is considered as output. The result is shown in Figure 11. It shows that no pole is located on the right hand side of the imaginary axis of S-plane, supporting stability of the microgrid system.

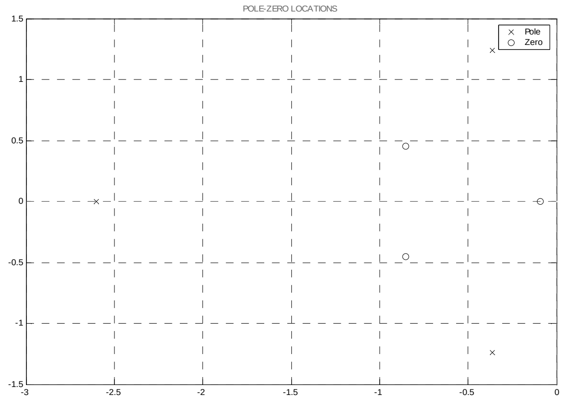


Figure 11. Pole-Zero mapping of microgrid

Polynomial Stability Test: The microgrid shown in Figure 8 above also studied for "Polynomial Stability Test" using Matlab Simulink tool box. This block is used to check the pole locations of the denominator polynomial, A(z), of a transfer function, H(z) as mentioned below in equation (3).

$$H(Z)=[B(Z)/A(Z)]=\{b_1+b_2Z^{-1}+\ldots.+b_mZ^{-(m-1)}\}/\{a_1+a_2Z^{-1}+\ldots.+a_nZ^{-(n-1)}\} \quad (3)$$

The poles are the n-1 roots of the denominator polynomial, A(z). As is typical in DSP applications, the transfer function above is specified in descending powers of z-1 rather than z. "The Polynomial Stability Test Block" uses the Schur-Cohn algorithm to determine whether all roots of a polynomial are within the unit circle. If any poles are located outside the unit circle, the transfer function H(z) is unstable showing zero (0) at the output of the Simulink test block. For the system to be stable, the output of the block should display the value one (1). After simulation of the current system, the value 1 is obtained at the output of the "Polynomial Stability Test Block" indicating that the polynomial in the corresponding column of the input is stable.

5. Conclusions

Renewable energies are environmentally focused but the output power fluctuation of renewable energies may cause excess variation of voltage or frequency of the grid. Increase in the amount of renewable energies would violate the quality of the grid [8, 9]. To maintain the quality of the grid, the design of a microgrid should meet some specific criteria which can judge its performance. There are many factors responsible towards smooth integration of the DERs to form microgrid. Eventually, all the possible factors should be considered at the stage of research and development prior to the system put in actual operating mode for effective utilization of R&D cost. Among many prime factors, a microgrid must be studied for stability at design level. It is necessary to develop suitable tool or method to check the stability criteria of a proposed grid. In this paper, the authors have suggested few methods to study the dynamic stability of a proposed microgrid due to sudden fluctuation of load by representing each component of the microgrid in the form of their transfer function. It is realized from this work, that there are many features such as linearity or non linearity of the system, gain, time constants, etc. which decide the transfer function of a DER and the transfer function may vary as per the assumptions considered for those factors even for the same system. So the stability analysis has many dimensions to be dealt with in the future research work. Further research efforts will attempt to accumulate all the possible factors for integration of distributed energy resources and stability analysis of microgrid. Progress of this research will be reported in due course.

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