Asian Journal of Water, Environment and Pollution, Vol. 21, No. 6 (2024), pp. 59-67.
DOI 10.3233/AJW240073

Renewable Energy Based Stability Solution for Grid-Connected Distribution System

Abinash Singh* and Balwinder Singh Surjan[1]
University Centre for Research & Development, University Institute of Engineering, Chandigarh University, Punjab, India
[1]Department of Electrical Engineering, Punjab Engineering College (Deemed to be University), Chandigarh, India
✉ profabinashsingh@gmail.com

Received February 27, 2024; revised and accepted March 22, 2024

Abstract: System stability and power quality are the most incredibly essential requirements of a power system. Renewable Energy sources of electricity help in meeting the load demands of consumers in a clean and efficient manner. Microgrids and FACTS devices are used as environmentally friendly solutions to feed customers while preserving the stability of the power supply. This research work presents a stability examination of a distribution system having a microgrid with and without GUPFC under various fault conditions like LG and LL faults. The simulation results obtained using MATLAB/SIMULINK for such arrangements are presented in this work. It is found that Microgrid makes the power system more environment friendly and GUPFC successfully mitigates voltage sag occurring during fault conditions and helps in performance enhancement of the system by improving frequency and ISE.

Key words: Power system stability, renewable rnergy, microgrid (MG), FACTS, fault, GUPFC.

Introduction

The depletion of fossil resources has accelerated, while global energy use has expanded rapidly and has adversely affected our environment (Kumar and Rao, 2015; Sharma et al., 2023). Since the expansion of science and electricity in our globe, the demand for energy has increased to meet our enhanced lifestyle, posing a burden on the power system network. Various factors like increased industrialization, lavish lifestyle, enhanced with the latest control, automation, and online services have resulted in fast exhaustion of electrical energy and increased pollution (Abo-Al-Ez et al., 2012; Thakur et al., 2022; Singh et al., 2020).

Singh and Surjan (2018) stated that coordinated operation is increasingly necessary for linked networks to avoid the detrimental effects of a component breakdown. Combining several power sources can help achieve the increased availability and dependability of electrical power needed for a variety of applications (Arulampalam et al., 2010; Dhivya and Dhamodharan, 2013). Infrastructures for transmission and economic distribution are needed in order to supply customers with bulk electricity. The main goal of system design should be to provide the load end voltage while maintaining it within the established limits (Singh and Surjan, 2013; Van Cutsem, 2000). Because of the aforementioned factors, power quality and system stability have emerged as a key area of research (Alexander and Thompson, 2007; Shankar and Kundur, 1994; Van Cutsem and Vournas, 2007)

Khamis et al. (2012) and Singh and Surjan (2014) described that the use of renewable energy systems has increased energy consumption, reliability, and the capacity to fulfil the growing demand for power and furthermore to combat the increased heat produced by

*Corresponding Author

using traditional fuels. The concept of a microgrid (MG) was brought up to increase power supply efficiently by combining multiple energy sources at the distribution level and reducing pollution (Chukka et al., 2014; Honarmand et al., 2014; Singh et al., 2021).

Vinkovic and Mihalic (2009) and Singh and Surjan (2016) reported that in most circumstances, power quality is the quality of the received voltage. Due to rising deregulation and overloading, the power system must be safeguarded for which, a power electronics-based technology named Flexible Alternating Current Transmission Systems (FACTS) has been brought up (Abasi et al., 2020; Vilathgamuwa, 2003). FACTS devices intend to improve the power quality and system stability by controlling different parameters of the power system because customers have become more aware of numerous power quality issues and their consequences (Awad et al., 2021; Pambudy et al., 2014; Sharma et al., 2022). GUPFC is the best FACTS device for voltage mitigation (Pambudy et al., 2014; Singh et al., 2016, 2021)

With the aim of examining the system stability and performance during fault conditions, the microgrid (MG)-enabled power system with and without FACTS device has been implemented in this work. The structure of this document is as follows: Section: Introduction, section: System Description. Then the section: Simulation Results are presented and discussed and in the end Conclusion along with future scope is the last section.

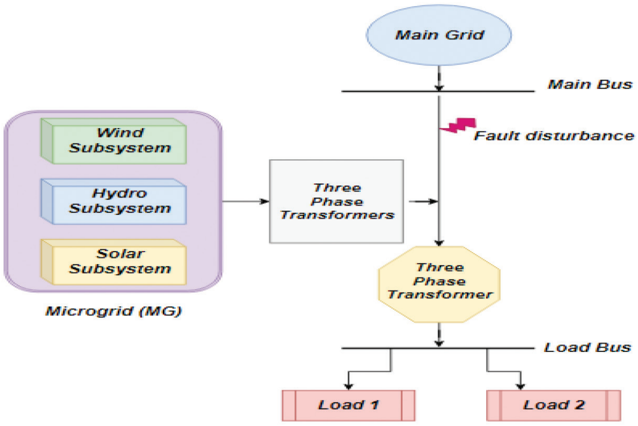


Figure 1: Test system embedded with MG in fault disturbance mode.

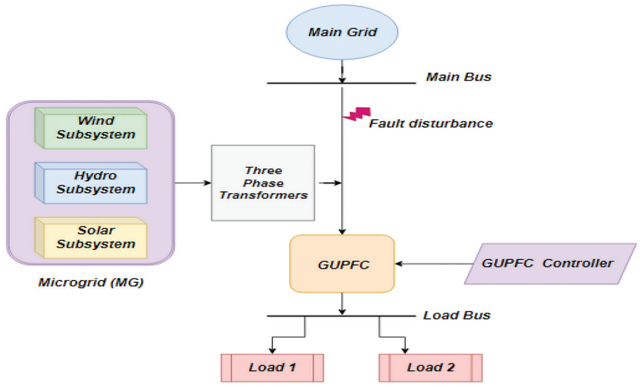


Figure 2: Test system embedded with MG & GUPFC in fault disturbance mode.

System Description

The main system and subsystems under consideration have been modelled in MATLAB/SIMULINKas specified in Figure 7. The base system consists of a main grid and two identical loads. The faults are introduced for short time period (0.7 sec) using three phase fault block from the SIMULINK library.

MG Modelling

Implementation of MG in the main system is presented in Figure 1 and Figure 2, producing power at a 400V voltage level which is connected to the test system. The microgrid block contains three renewable energy sources viz. hydro, solar and wind sub-systems. The consideration of purely renewable energy sources makes MG environmentally friendly.

Wind Power Plant

MATLAB/SIMULINK has been used for building the required model. A wind turbine block is available in the SIMULINK library and it is required to give torque as input to the induction machine present in the DFIG (Doubly fed induction generator) system. The DFIG subsystem internal model consists of an asynchronous machine block (which has been implemented as an induction generator), and two converters feeding the induction generator from both the rotor and grid side with a common DC link between them. DFIG controller provides pulses for both grid side and rotor side converters present in the DFIG block. In this controller dual stage fuzzy control has been proposed. The final output of the wind sub-system is connected to the main system through a transformer as shown in Figure 3.

Hydro Power Plant

The SIMULINK model has been developed in MATLAB software to suit the work as depicted in Figure 4. The synchronous machine block has two inputs Pm and Vf, which it obtains from the hydraulic turbine and excitation system blocks respectively and then it is connected to the test power system for transmitting a three-phase power supply. Another output of the synchronous machine is connected to the measurement block for measuring its machine parameters. The measurement block measures the machine parameters of the synchronous machine and also splits these parameters separately so as to satisfy the input demands of hydraulic turbine and excitation system blocks.

Solar Power Plant

The SIMULINK model for the solar power plant consists of a constant irradiance supply given to solar cell arrangement, which is connected to an inverter for DC/AC conversion of voltage and is further connected to the main test power system through a transformer. Fuzzy logic-based inverter control is implemented in the solar power plant which implements the control of voltage output of the solar subsystem, giving output to the PWM generator which in turn supplies pulses to the IGBT-based inverter as presented in Figure 5.

Generalised Power Flow Controller

It is the newest FACTS device having single shunt and 'n' series compensating devices. The GUPFC's MATLAB/SIMULINK model has been integrated with the main system on the basis of the layout diagram shown in Figure 6.

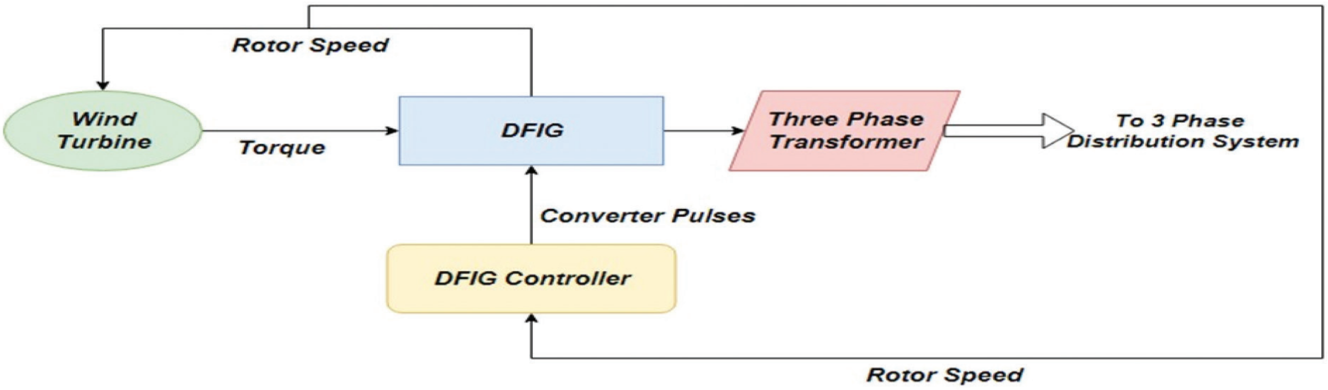


Figure 3: Wind power plant concept model.

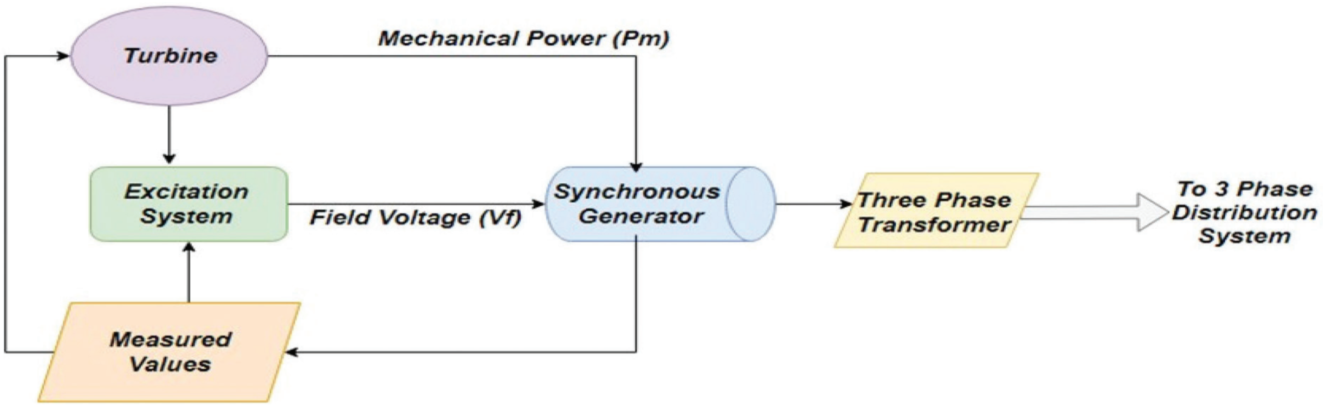


Figure 4: Hydro power plant concept model.

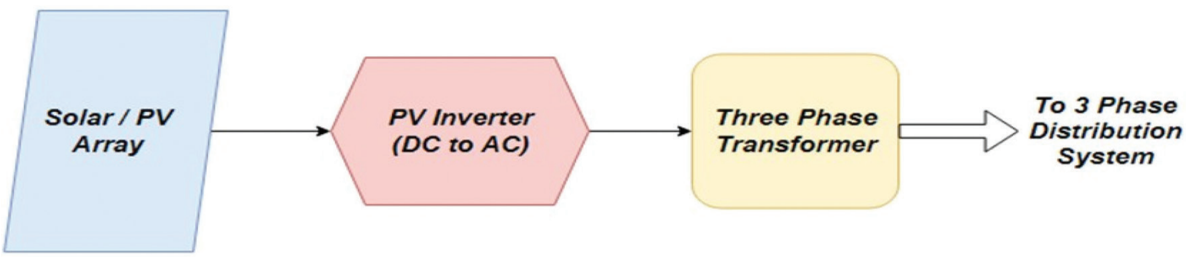


Figure 5: Solar power plant concept model.

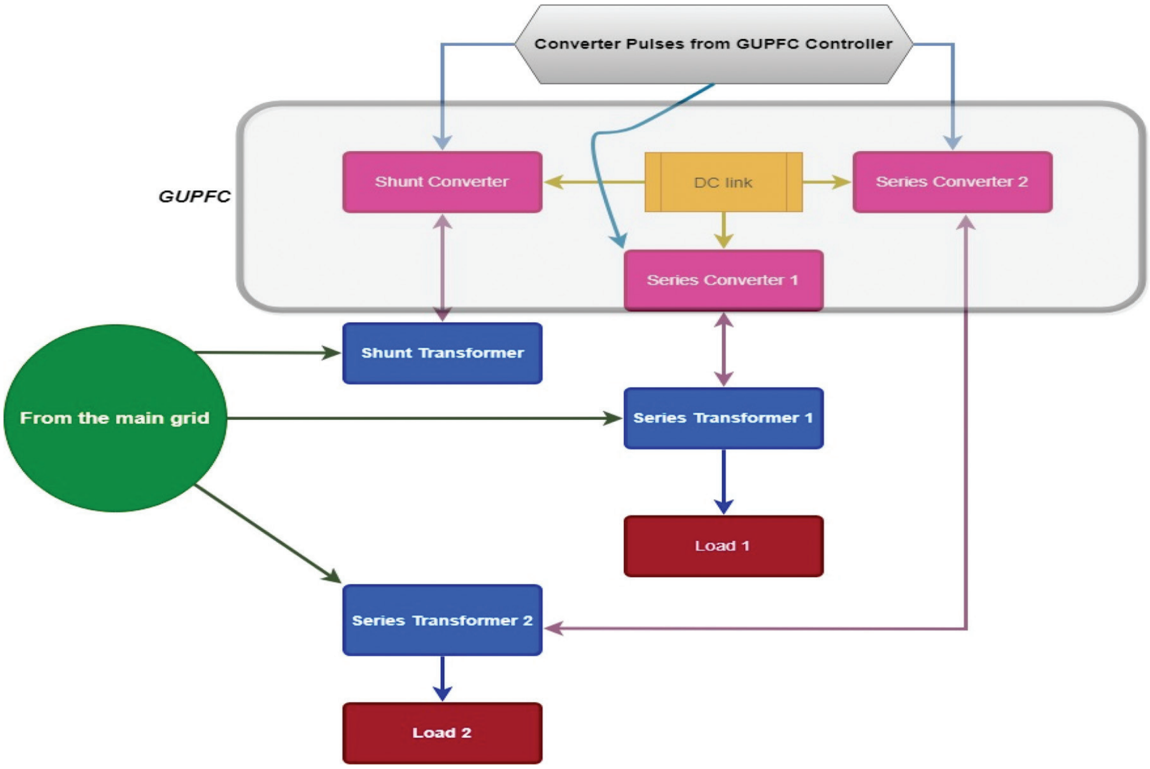


Figure 6: System with GUPFC concept model.

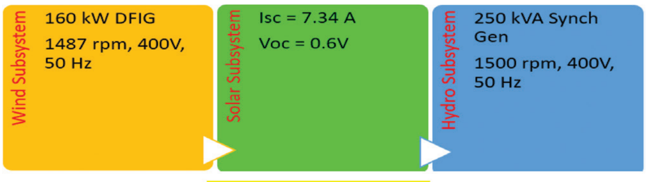


Figure 7: System Specifications

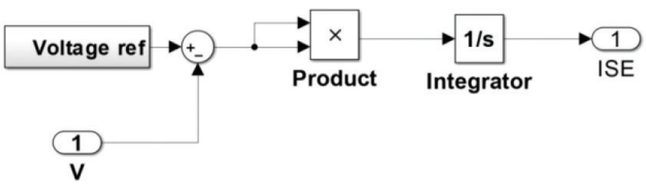


Figure 8: SIMULINK model of subsystem block ISE in test system.

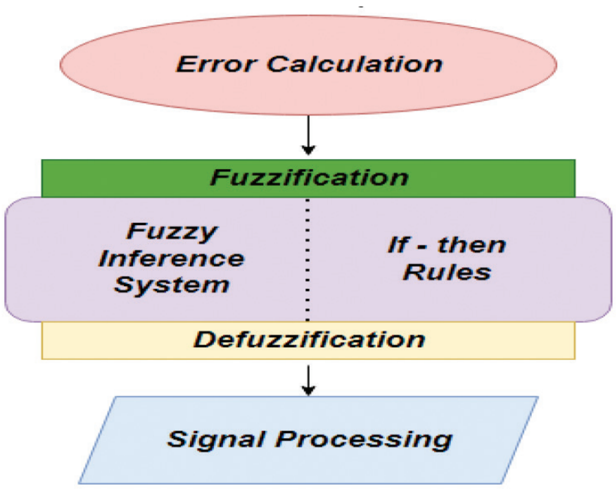


Figure 9: Fuzzy logic controller system process.

Integral of Squared Error

Figure 8 illustrates how SIMULINK has modelled the integral of the Squared Error (ISE) performance metric.

Fuzzy Logic Controller (FLC)

Fuzzy logic controllers have been used in wind, and solar energy systems and in GUPFC as converter controllers. FLC has different stages of operation as illustrated in Figure 9. It includes processing of the inputs (error and error rate) into fuzzy membership functions, followed by the application of if–then rules to obtain the output for the defuzzification process and in the end signal processing is done to convert the output into 'abc' form for PWM generator to obtain the pulses required by convertors (Albatsh et al., 2014; Boulâam et al., 2014; Özbay et al., 2010; Shiva et al., 2022).

Results and Discussions

The simulation results obtained for different systems undergoing fault disturbances have been presented below:

Line to Ground (LG) Fault

The base system without any MG and also without GUPFC has been taken as a reference. LG fault has very little impact on the power system under consideration with small voltage and power reduction. ISE performance index has increased from the base reference value showing some instability. All three renewable energy sources viz. hydro, solar and wind are altogether connected to the base system & GUPFC is further connected with it as given in Figure 6 and following results are obtained:

The introduction of the LG fault to the base system for 0.7 seconds duration, resulting in a minor disturbance of small sag in voltage. This fault disturbance is not very dangerous for the system as can be seen from Table 1, however, the value of the ISE performance index increases from 0.02007 to 0.02032 which is a slight variation. The results shown in Figure 10 to Figure 12 clearly show that with the implementation of GUPFC along with MG, power system stability is maintained throughout all parameters and the ISE performance index is also having a value nearer to the reference value (0.0200).

Line to Line (LL) Fault

After analysing system performance on the LG fault, the next fault under consideration here is the LL fault.

Table 1: Frequency and ISE values for systems during LG fault

Type of Arrangement	*Peak frequency value*	*Frequency's minimal value*	*Final ISE value*
Base System	50.214	49.780	0.02032
System having MG	50.205	49.787	0.02014
System having MG and GUPFC	50.110	49.945	0.02001

Again, the three systems are observed for changes in parameters on the load side due to the effect of LL fault for the same time duration of 0.7 sec. Afterwards, GUPFC is also incorporated to improve system stability. During this fault occurrence time, the voltage is reduced to 50 %. Moreover, there are some frequency variations too. ISE performance index value rises abruptly to a high value showing the loss of stability in the system. The simulation results for the base system are presented along with the results of the system with MG and GUPFC. From Figure 13 to Figure 15, it can be seen that the MG is only able to restore a very small amount of voltage and the system needs more stability and reliability as the ISE value is still far from the reference value (0.0200).

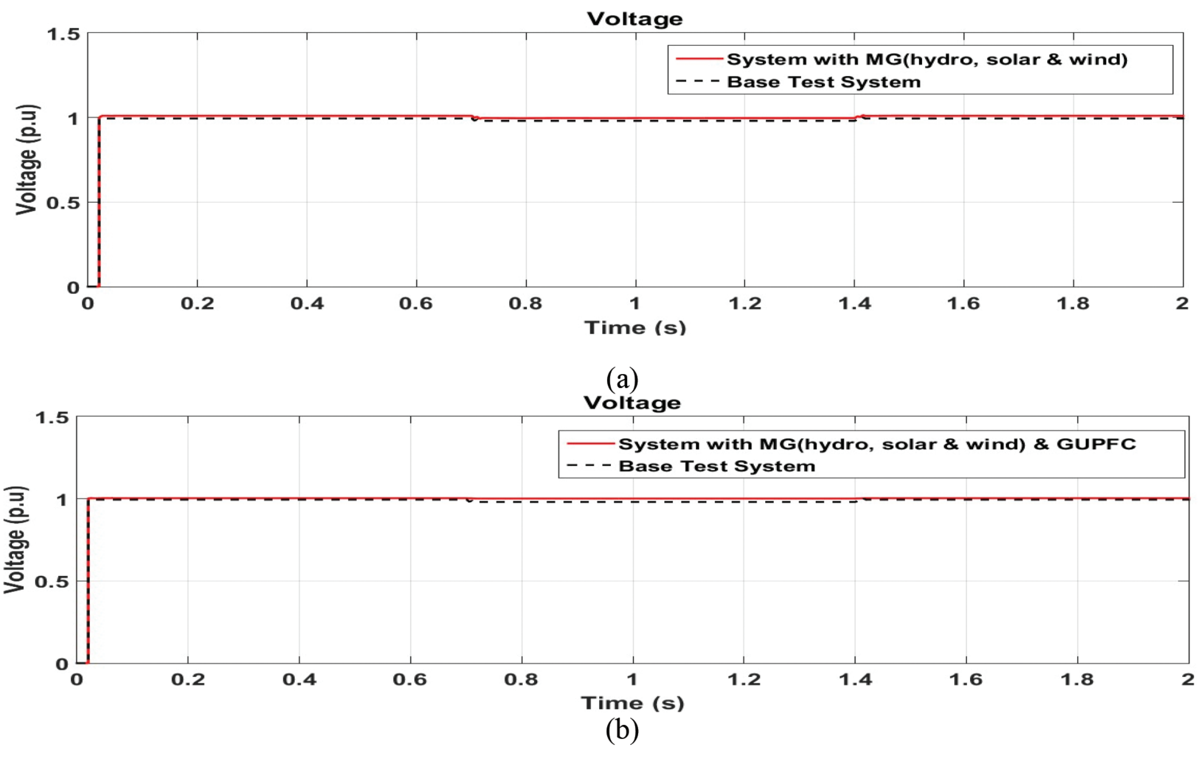


Figure 10: Load side voltage for system with MG (a) without GUPFC and (b) with GUPFC, during LG fault.

The simulation results presented above from Figure 12 to Figure 14 indicated that GUPFC helps MG to meet the demands of the load side during the disturbance and the system maintains stability and performance with the help of GUPFC which can be seen from the ISE performance graph.

As compared to the LG fault, the effect of the LL fault is found to be more severe in every parameter waveform for the base system as given in the above results. Both voltage and frequency are affected due to this disturbance. Both MG and GUPFC combinations did their part of restoring the system stability which is

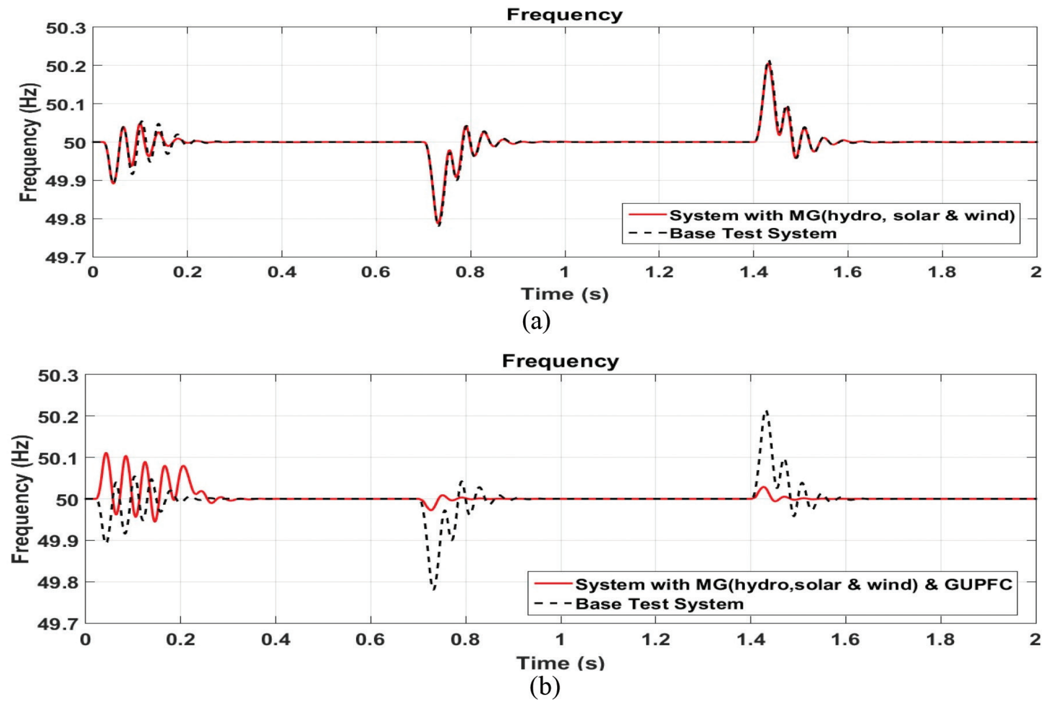


Figure 11: Load side frequency for system with MG (a) without GUPFC and (b) with GUPFC, during LG fault.

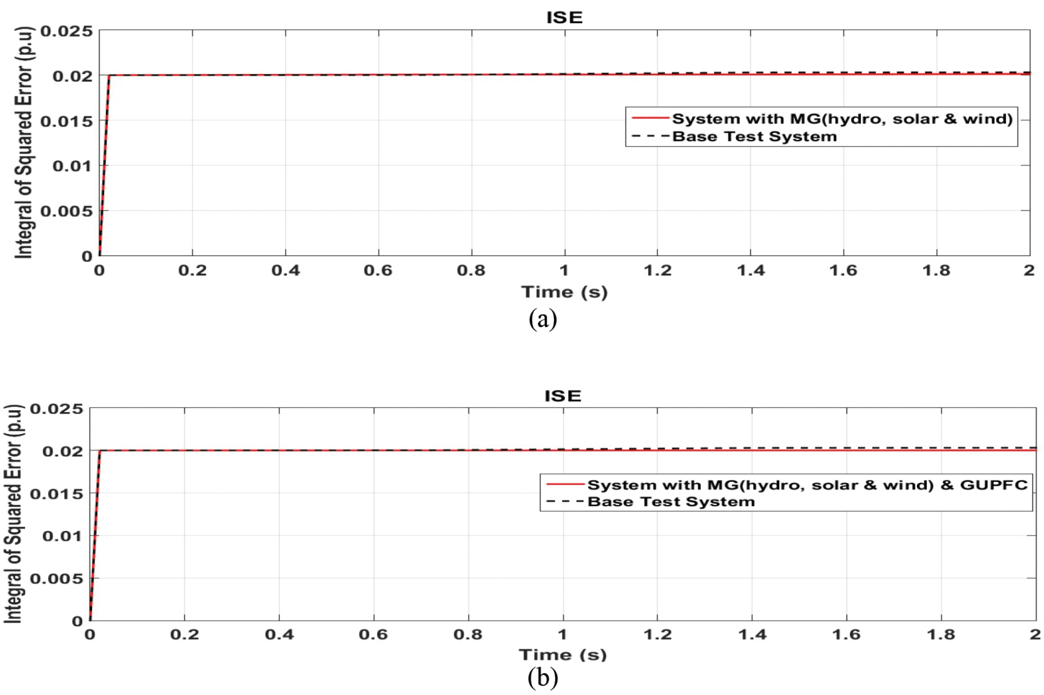


Figure 12: Load side ISE for a system with MG (a) without GUPFC and (b) with GUPFC, during LG fault.

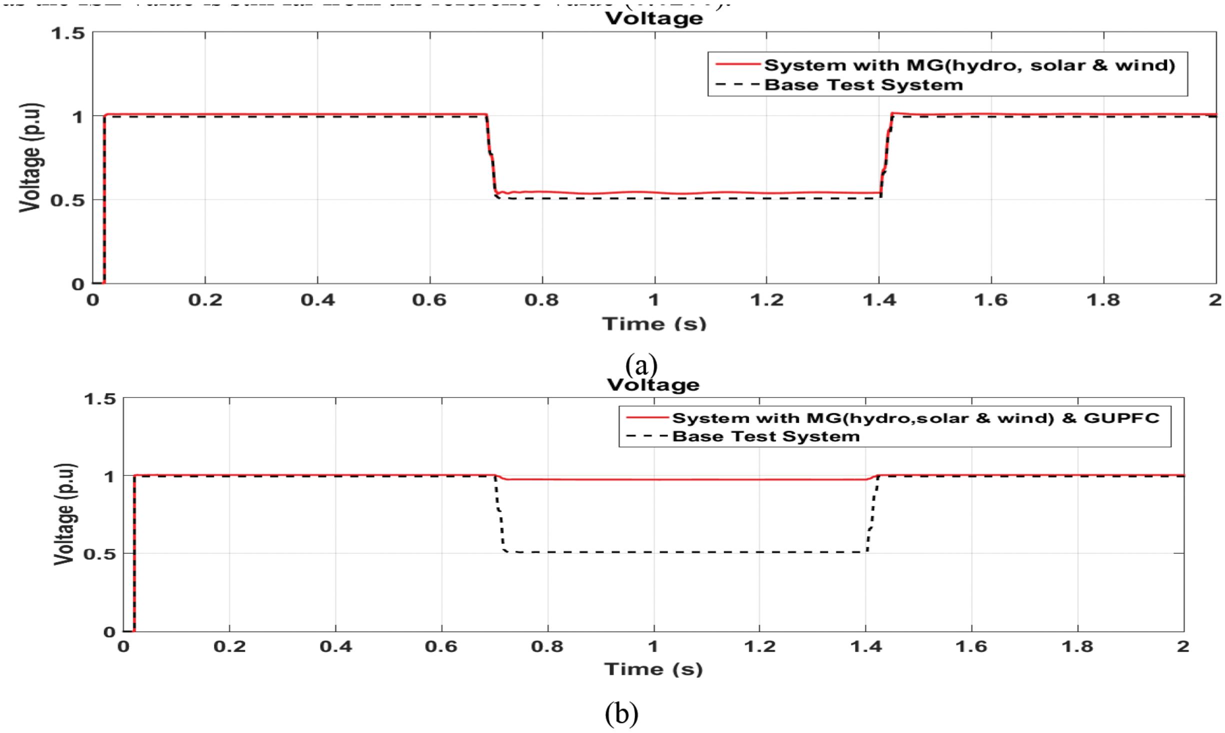


Figure 13: Load side voltage for system with MG (a) without GUPFC and (b) with GUPFC, during LL fault.

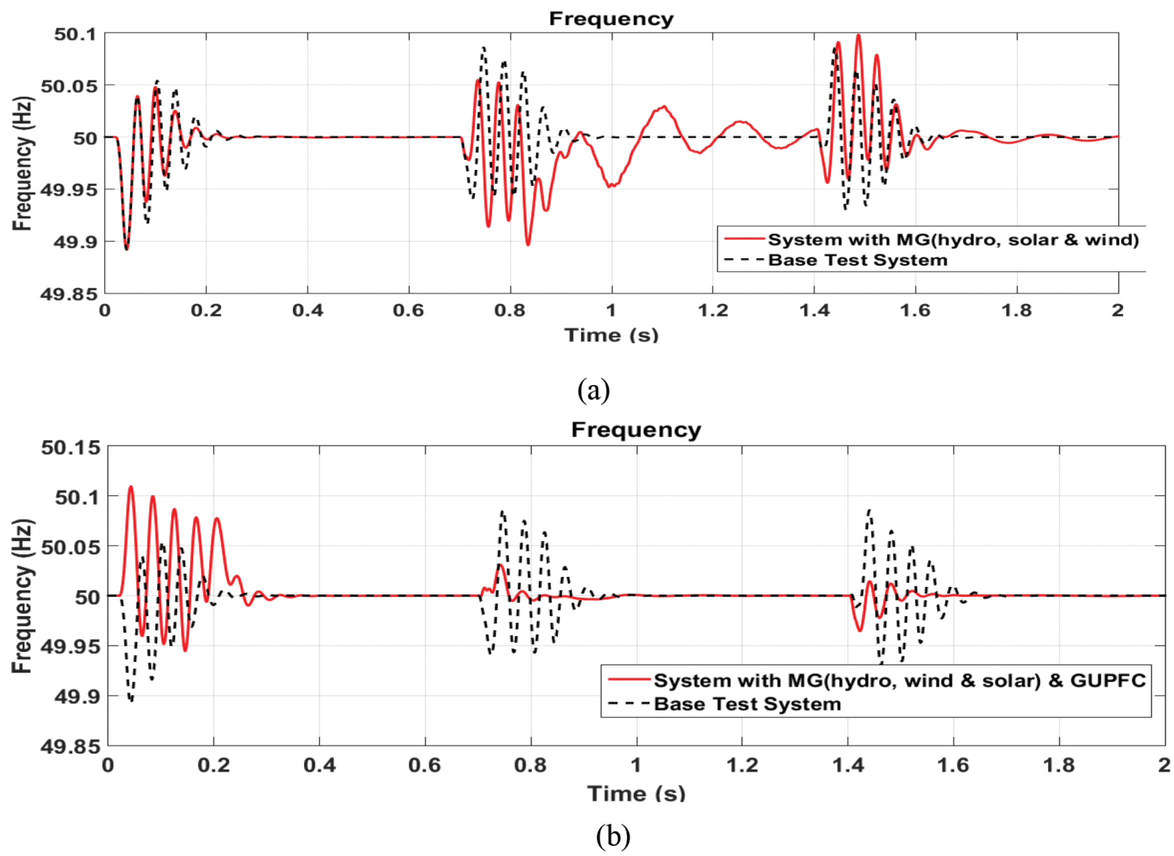
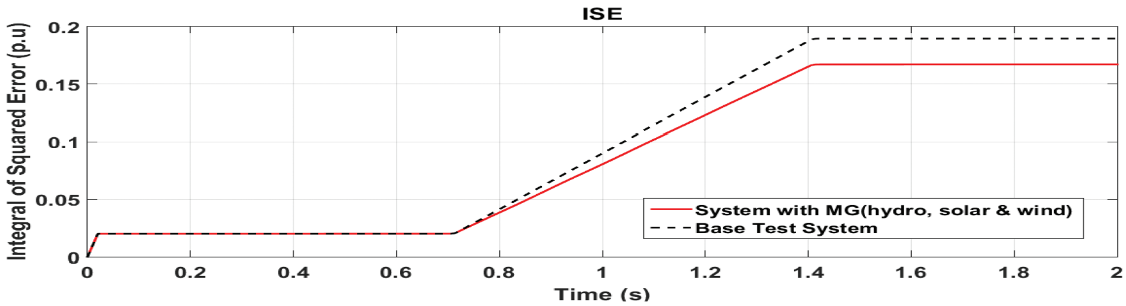
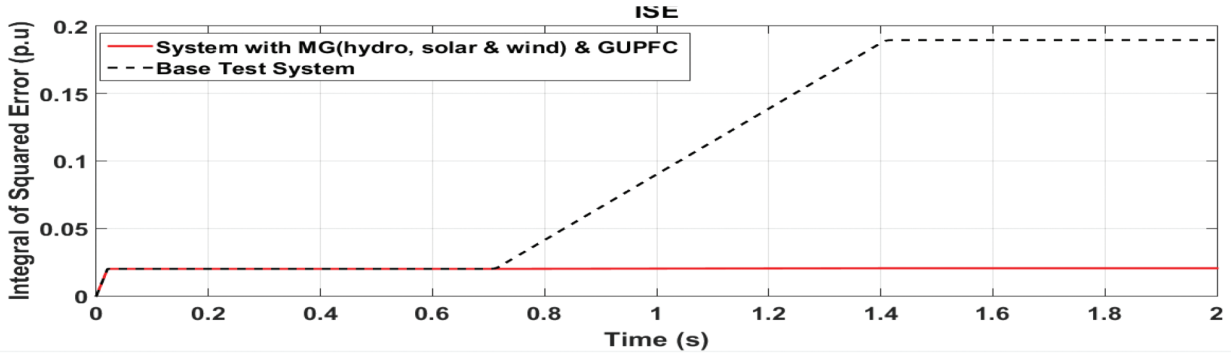


Figure 14: Load side frequency for system with MG (a) without GUPFC and (b) with GUPFC, during LL fault.



(a)



(b)

Figure 15: Load side ISE for a system with MG (a) without GUPFC and (b) with GUPFC, during LL fault.

clear from the results and deeper system performance is judged by ISE index values. GUPFC has increased the stability of the system and voltage quality as it's clear from Table 2. It is evident from the results that GUPFC is overcoming the fault disturbance and subsidizing its effects to its best. Voltage requirements are fulfilled and the frequency waveform is also free from unwanted fluctuations with ISE value closer to a reference value.

Table 2: Frequency and ISE values for systems during LL fault

Type of Arrangement	*Peak frequency value*	*Frequency's minimal value*	*Final ISE value*
Base System	50.086	49.892	0.1896
System having MG	50.098	49.892	0.1672
System having MG and GUPFC	50.109	49.945	0.02048

Conclusion

The power system behaviour has been observed during different fault conditions and system stability deviations were noted when MG is connected to the main system with and without GUPFC for proposing a renewable energy-based environment-friendly solution. During the LG fault, the system does not lose its stability much due to very little voltage variation but during the LL fault, the system undergoes higher voltage sag and large frequency variations. GUPFC along with MG has aided the system in maintaining stability and quality of electricity and voltage under various failure scenarios. The system retains its power system stability with the help of GUPFC by mitigating voltage sag up to 90 %. The system performance can be examined from the improved ISE values. Thus, the GUPFC not only saves the system from fault disturbances but also eliminates any little impacts that MG may have had on the system. In the future, coordinated operation of FACTS devices and microgrids can be proposed for an efficient smart grid operation providing uninterrupted power to consumers in an ecofriendly efficient manner.

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