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Power system stability investigation through smart control of micro grid and GUPFC

Abinash Singh[a*] & Balwinder Singh Surjan[b]
[a]Chitkara College of Applied Engineering, Chitkara University, Punjab 140 401, India
[b]Punjab Engineering College (Deemed to be university), Chandigarh 160 012, India

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System stability is the utmost requirement for a power system. In order to provide quality power to consumers while maintaining power system stability, Microgrid and FACTS devices are introduced. A smart control strategy is essential for a Microgrid system that automatically controls the MG's operation from non-autonomous to autonomous and vice versa. This research work proposes a similar smart connection between the Grid and the Micro Grid along with GUPFC for system stability and voltage quality after analysing On-Grid and Off-Grid performance of the power system having microgrid under various operating conditions. The MATLAB simulation results for such combination are presented.

Keywords: Distribution network, FACTS, Fault, Power quality, Voltage stability

1 Introduction

Since the growth of electricity and science, our updated life style has increased our electric power consumption, which has resulted in a liability on the power system distribution and transmission systems[1]. Electricity consumption has increased as a result of rapid industrial growth, increased usage of high-tech power electronic equipment, and advanced control systems. As a result of these considerations, there has been a surge in research in the area of power quality and stability. In a linked network, the breakdown of any electrical component can have significant implications[2,3]. Blackouts and unexpected voltage drops can become a stumbling block in the process of meeting critical power demands while transmitting bulk electricity to consumers, therefore the power system has to perform efficiently within the range of its prescribed limits[3-5].

In most circumstances, power quality has been defined as the quality of the voltage received on the load side. With the increase in customer intelligence, utilities must continue to provide power that is both high in quality and stable. As a result, service providers have aimed to keep voltage within specified ranges. Flexible Alternating Current Transmission Systems (FACTS) technology has been designed to improve the quality of power received by regulating many aspects of the power system[6,7].The ability of the power system to maintain voltages at all system buses within accepted ranges during normal operating conditions or after a disturbance is regarded as voltage stability[8,9].

The combination of small generation systems with low voltage distribution systems is referred to as a micro grid. Micro Grids can be created using clean energy from fossil fuels and renewable energy sources. MGs can be used with or without a link to the main grid to meet the ever-increasing demand for electricity while also improving reliability and energy efficiency[10-13].

The MG have assisted in the restoration of voltage during islanded mode with minimal impact on the system during grid connection, as well as the maintenance of power quality[10]. However, in this work a combination of MG and FACTS devices have been used to analyse power system performance during fault scenarios.

The manuscript begins with a brief introduction, followed by a detail of the test system, then modelling of the GUPFC and Micro Grid, and finally the test system's responses are presented and inferences are concluded.

2 Materials and Methods

2.1 Test Power System Modelling

Figures 1(a and b) displayed a line diagram of the test power system that was modelled in MATLAB/ SIMULINK and used as a reference system for future investigation. As illustrated, the power system under examination comprises a three phase supply of 0.4 KV and two permanently linked three phase loads (75 kW each).

*Corresponding author (Email: profabinashsingh@gmail.com)

In order to provide 0.4 KV voltage supply in the power system, a 3-phase source block was used in the main grid subsystem of SIMULINK model. Voltage, current, and ISE (Integral of Squared Error performance index) are the parameters that have been considered for simulation analysis. ISE has been determined on voltage in this work and can be stated as in Eq. (1):

$$ISE = \int_0^\infty e^2(t)dt \qquad ...(1)$$

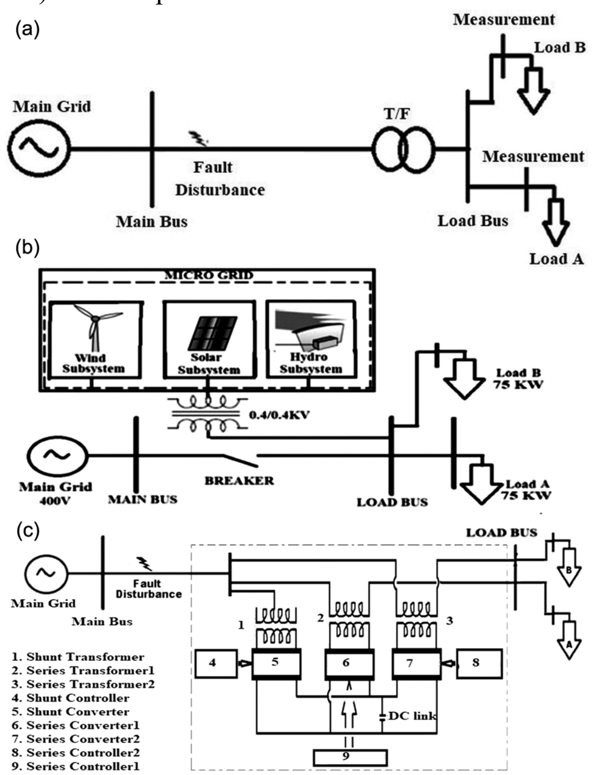

Fig. 1 — Test system, (a) overall architecture, (b) system with Microgrid layout model, and (c) system model with GUPFC.

2.2 Micro grid

Microgrid comprising of solar, hydro and wind energy sources has been implemented with test system in connection to main grid via normal P.C.C (point of common coupling) and the simulation results were obtained without any fault disturbance. These results verified the proper working of microgrid with main grid and also in islanded mode[10].

2.3 FACTS Devices

FACTS devices have been suggested to improve transfer capacity, system stability and to reduce system losses by the bus voltage regulation[14]. GUPFC is a multi-line FACTS device of the newest generation, with combined controllers, n number of series controllers and a single shunt, where the number of lines equals the number of series controllers. When compared to other FACTS devices, GUPFC ensures equivalent simulation results for multiline systems, as well as the optimum performance[15]. The GUPFC model has been implemented in test system according to Fig. 3. On the basis of this connection topology, the shunt and series convertors were connected to the system through 3-phase transformers. Fuzzy logic-based controllers were used to operate the shunt and series convertors. The methodology of abc to dq0 and vice-versa has been followed here. An abc signal generated by each

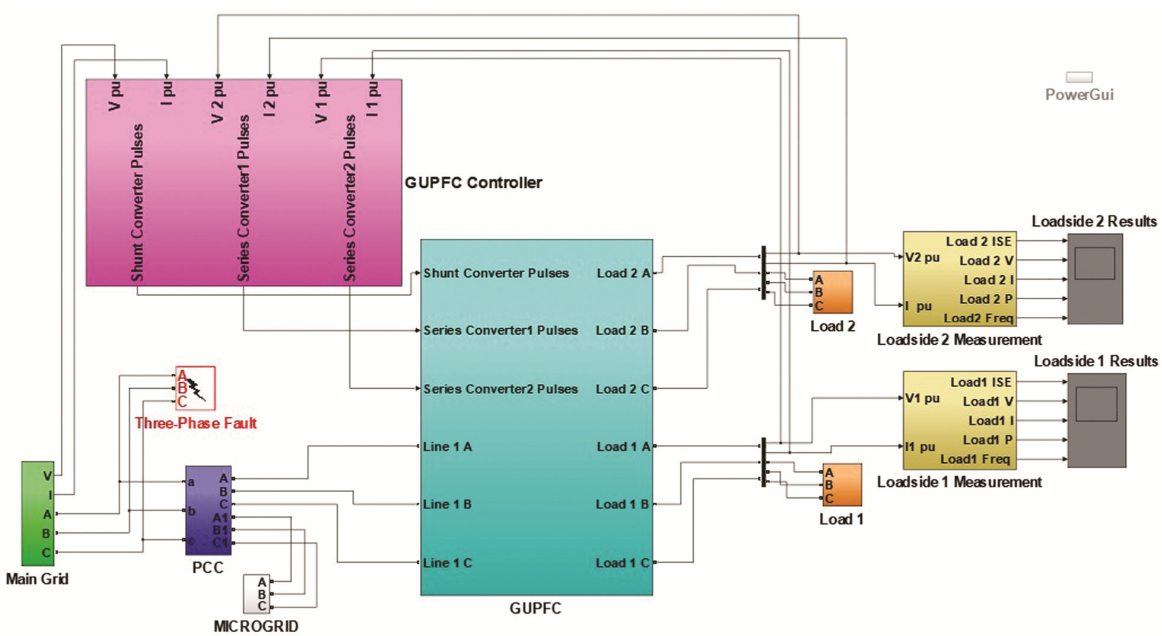

Fig. 2 — Proposed model for test system having MG connected via smart P.C.C and GUPFC.

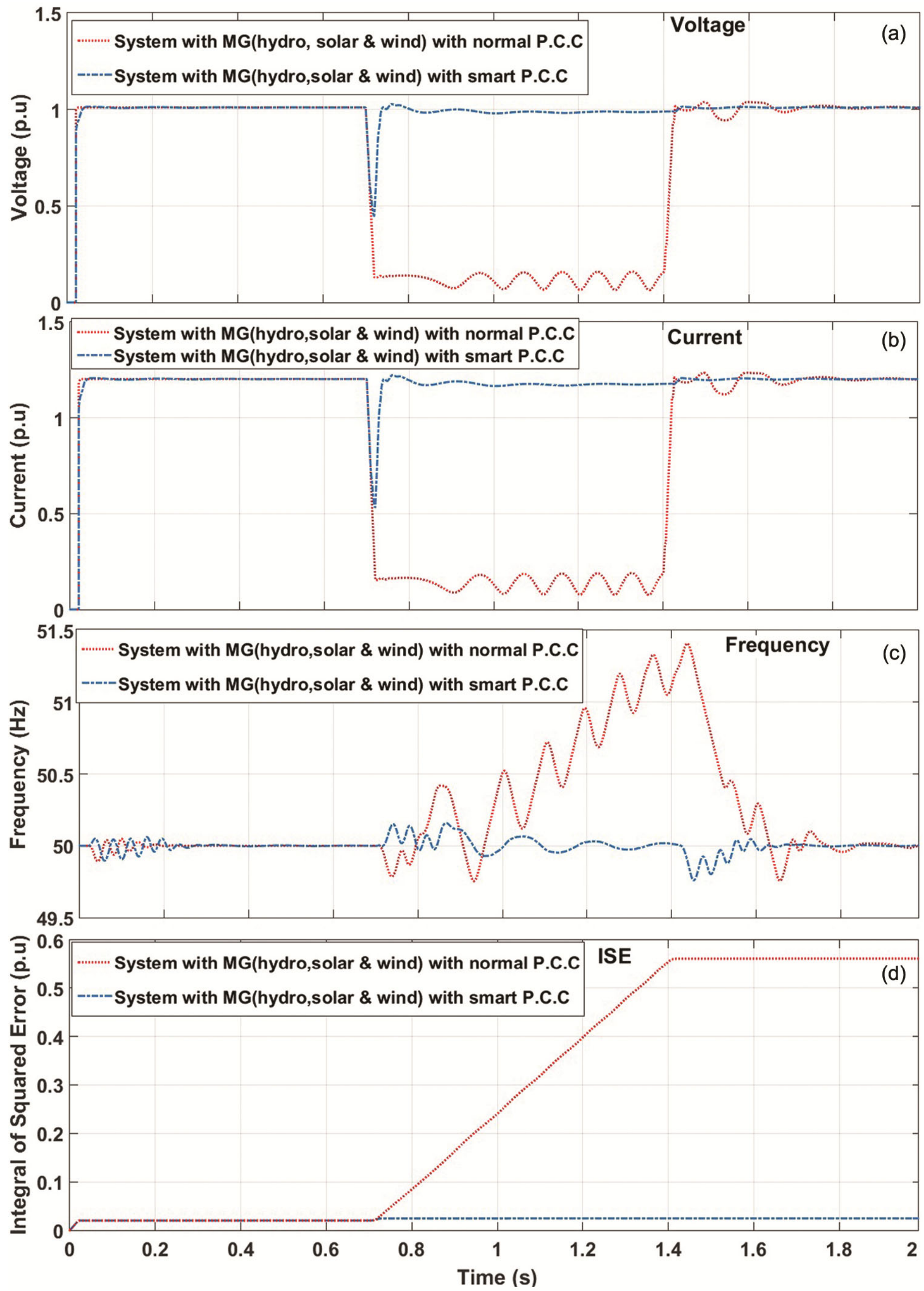

Fig. 3 — Test system with MG without GUPFC during LLLG fault, (a) Load side voltage, (b) Load side current, (c) Load side frequency, (d) Load side ISE.

controller has been converted to the pulses through PWM and then these pulses were supplied to their respective shunt or series convertors.

2.4 SIMULINK Model

From Fig. 4, it can be seen that microgrid has been connected at P.C.C (point of common coupling), wherein an automatic real time smart operating switch has been implemented which senses the voltage magnitude and compare it with reference value (1 p.u) and work accordingly to either operate in islanded mode or stay in grid connected mode. In this way the consumer end can be ensured for continuous power supply in cases of faults and grid failure and thus MG has been tested in both modes simultaneously on real time automatic operation analysis. GUPFC has been used to restore the voltage during fault condition.

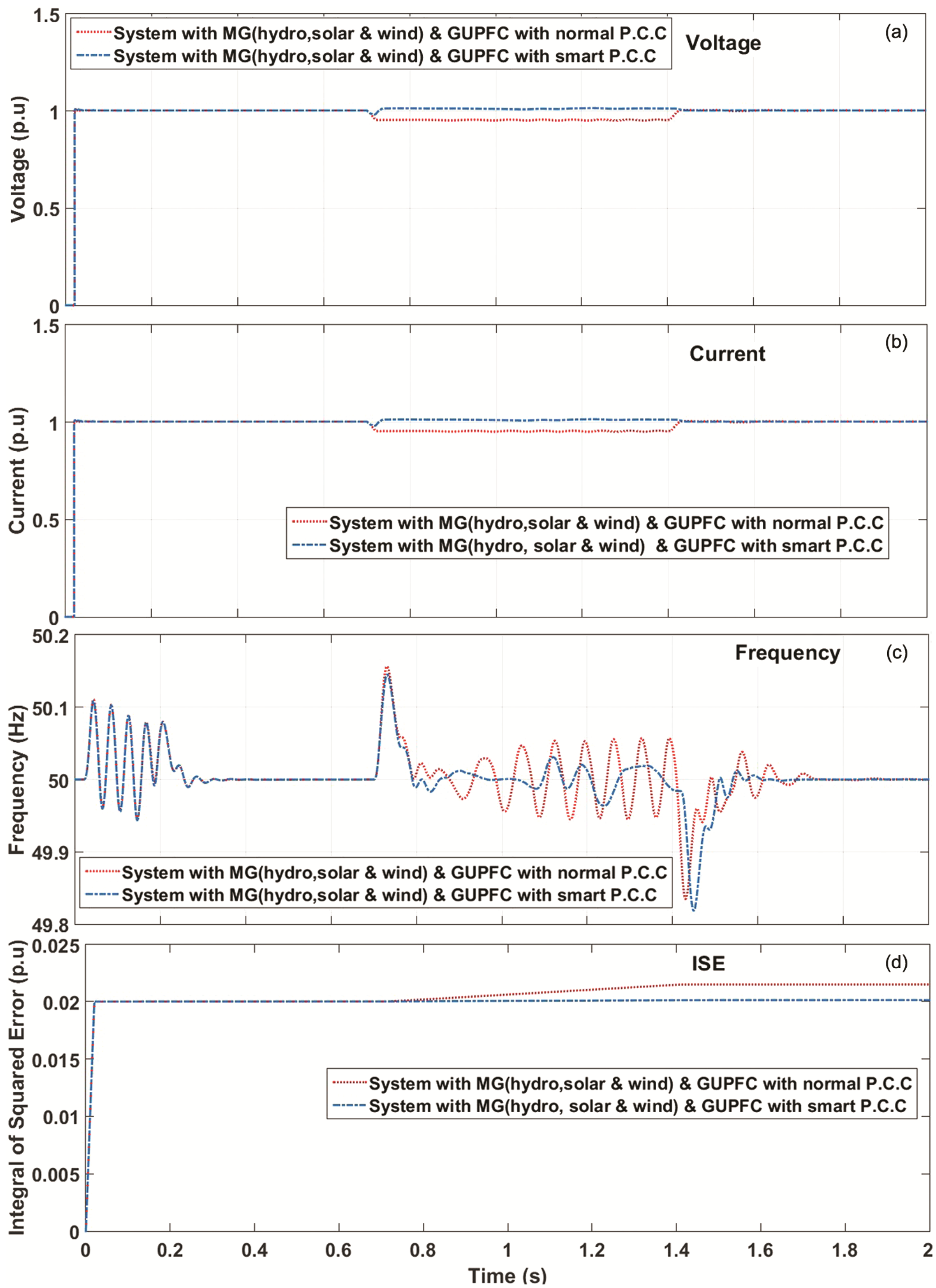

Fig. 4 — Test system with MG and GUPFC during LLLG fault, (a) Load side voltage, (b) Load side current, (c) Load side frequency, (d) Load side ISE.

3 Results and Discussion

The simulation results have been obtained for this combination in proposed model (with smart P.C.C) for the case of LLLG fault only (as it is one of the most severe fault). Corresponding results have been presented below showing the comparison with the results of system connected through normal P.C.C. Two cases were taken into consideration: System with only MG (hydro, solar and wind) without GUPFC and system with both MG (hydro, solar & wind) and GUPFC for both normal P.C.C and smart P.C.C connections under fault condition.

From the results, it can be seen that for time period of 0.7 to 1.4 sec., LLLG fault disturbance effects voltage, current and frequency. There has been an increase in the ISE value signifying reduction of performance of system thus making it unstable during fault disturbance period.

3.1 Base test system with MG having wind, solar and hydro energy sources

All three renewable energy sources were considered in MG, connecting with base system firstly via normal P.C.C and then with smart P.C.C and corresponding parameter results have been obtained as below:

From simulation results displayed in Fig. 5 to Fig. 8, it is evident that during LLLG fault, the test system with MG connected through normal P.C.C has undergone voltage sag and correspondingly a great amount of instability occurred in current and frequency waveforms during fault period. But with proposed method of connecting MG via smart P.C.C gave better results for all parameters. The smart P.C.C connection improved the performance of system and it has been justified from ISE performance index value which reached much closer to reference value as given in Table 2.

3.2 Base test system with MG having hydro, wind & solar energy sources and GUPFC.

In this case the GUPFC was also connected to test system along with all three energy sources of MG. Again both connections are taken into consideration, normal and smart P.C.C. The obtained results for this case have been presented from Fig. 9 to Fig. 12.

The results for this case clearly showed that the system performance improves to a great extent with addition of GUPFC. The incorporation of GUPFC even without smart P.C.C played significant role in removing voltage sag caused by fault. In the results, it can be seen that the voltage, current and frequency waveforms became more smoother during fault condition with the combined operation of GUPFC and MG with smart P.C.C. ISE performance index value has also been improved along with other parameters as compared to the value obtained for system with normal P.C.C. The frequency fluctuations have reduced for system with smart P.C.C & GUPFC as presented in Table 1 and Table 2. Now the system performance has considerably improved which is evident from the values of ISE very near to 0.02007 (reference value), thus ensured system stability and improved power transfer and the voltage has also been restored to required limit.

Table 1 — Frequency variation comparisons for proposed model during LLLG fault

System	Highest Frequency value	Lowest Frequency value
Base System	50.257	49.665
System with MG (wind, solar & hydro) with normal P.C.C	51.408	49.755
System with MG (wind, solar & hydro) with smart P.C.C	50.159	49.760
System with MG (solar & wind) and GUPFC with normal P.C.C	50.155	49.835
System with MG (solar & wind) and GUPFC with smart P.C.C	50.145	49.819

Table 2 — ISE performance index values for proposed model during LLLG fault

System	Value of ISE
Base System without fault	0.2007
Base System with fault	0.6533
System with MG (wind, solar & hydro) with normal P.C.C	0.5619
System with MG (wind, solar & hydro) with smart P.C.C	*0.0244*
System with MG (solar & wind) and GUPFC with normal P.C.C	0.0215
System with MG (solar & wind) and GUPFC with smart P.C.C	*0.0201*

4 Conclusion

This paper has discussed the introduction of smart P.C.C connection of Micro grid for enhanced stability and power quality and implementation of GUPFC along with it for improved performance of system. A comparative analysis between normal and smart P.C.C is displayed in the results for various system parameters like voltage, current and frequency. ISE performance index is used for performance analysis of system. From the simulation results, it can be seen that the deviations in waveforms caused by fault disturbance can be minimised with implementation of smart P.C.C connection of MG. GUPFC is incorporated in order to boost the system performance and maintain the stability of system even during disturbances caused by three phase fault and also nullify any minor effects caused by MG and its components in the system. MG connected via smart P.C.C along with GUPFC ensures the system stability and power quality completely and make the system to run continuously near its base reference values which can be depicted in Tables 1 and 2. Value of ISE verifies the improved performance of the coordinated operation of MG and GUPFC in both scenarios of normal and smart P.C.C. Proposed method of automatic real time switching from grid-connected to islanded mode leads to significant improvement in system's reliability and stability which is evident from the simulation results that makes the consumers to leave manual choice of power supply either from grid or from combination of MG & GUPFC. The ISE values for combinations of MG and GUPFC have also improved using proposed model with smart P.C.C. Comparative analysis of combination of various other FACTS devices with MG can be tried during fault conditions.

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