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Dynamic and Transient State Analysis of Islanded Microgrid

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***Abstract* -- Recent days have seen a high penetration of renewable energy resources bringing a drastic reformation of modern power system. The combined operation of renewable energy resources in power system introduced the concept of microgrid, which can efficiently satisfy the load demand in small scale power distribution. Under such circumstances microgrids are prone to several protection issues. Several topologies are incorporated to ensure protection in microgrid scenario. This paper proposes a proportional resonant based current controller which efficiently handles the protection issue under dynamic and transient state operation of microgrid. Several case studies are carried out in MATLAB Simulink environment and the results validated using proposed proportional resonant based microgrid model.**

***Keyword* – DERs, dynamic and transient state analysis, islanded microgrid, proportional resonant controller.**

I. INTRODUCTION

The expansive use of conventional practices to generate electricity is risking the environment balance due to excessive emission of greenhouses gasses. As a suitable sustainable alternative, Distributed Energy Resource (DER) based on Renewable Energy Resources (RES) like solar, wind, biomass, etc., has become popular due to their remarkable contribution towards power generation. When these DERs are interconnected & located adjacent to the consumers of medium or low voltage, and operating independently or in unison with the utility grid, they are often termed as MG. The advantageous functional features of MG are reliability, reduced transmission losses, reduced operational costs, easy integration of different renewable resources and local power supply with storage.

To match the fast escalation of electricity demand, the frequent integration of DERs in MG exposes it to numerous technical hazards regarding its operation. Of these, the crucial one is protection against any faults irrespective of its association with the utility grid or other microgrid. An efficient protection scheme should isolate the selective affected portion right after fault initiation to prevent the rapid proliferation of abnormal fault current.

Generally, distribution systems are radial, where unidirectional power flow takes place from substation to consumers through feeders. While grid is coupled with MG, over-current relay is sufficient to provide proper protection to the MG since the high magnitude of fault current is fed by the grid itself. But in absence of grid, islanded MG operation, the same protection scheme is not suitable due to the limited current. To address such crucial issues related to protection, numerous techniques are already incorporated in MGs like adaptive protection, differential protection, communication based adaptive protection topology based on level of fault current, appraising the effect of different modes of MG operation, dynamic behaviour of DERs and load parameter etc.

During faults in isolated MG, the fast detection and limitation of fault current is one of the indispensable area of concern. This paper introduces a flexible and simple current control technique based on static switch and solid state relay collaboration to safeguard the numerous current sensitive components of MG under dynamic state and transient state. Moreover, to improve the efficacy of the proposed topology proportional resonant (PR) controllers are incorporated in current control scheme to suppress the effect of voltage and current harmonic components.

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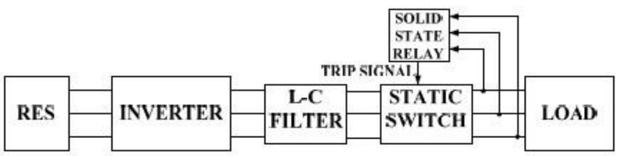
II. SYSTEM ARCHITECTURE

Figure 1 depicts the block representation of the proposed configuration of isolated MG. To investigate the performance of the proposed current controller, a simulation model is developed using discrete mode of MATLAB simulation software. The RES like solar, wind, geothermal etc., can be chosen as the source of MG depending upon their availability and can be integrated to meet the diversified demand. Since the DC input is transformed into AC equivalent using inverter, filtration of inverter AC output is essential to remove the higher order frequencies. Hence an L-C filter is designed to match the inverter output and load. As discussed earlier, conventional relay-circuit breaker duo is substituted by solid state relay and static switch combination, between filter and load, for faster response to restrict the proliferation of fault current among the current sensitive components of power system. Further, the feedback from the load assists in producing the proper PWM signal for the inverter.



III. CONTROL TOPOLOGY

Current decade emphasis on the adoption of MG in existing power system is due to the precedence like reduction of power transportation cost as well as reduced transmission line loss, availability of local power supply, reliability of service etc. However, the frequent penetration of DERs in MG is risking the protection of the current sensitive essentials of MG during faults as islanding suffers from the lack of short circuit current levels due to absence of utility grid. Moreover, intentional islanding of MGs during faults may invite the difficulties in term of power quality, frequency stability, security etc. Thus protection against faults should be capable to safeguard MG against fault during absence of utility grid without compromising the power delivery capacity of MG.

The abnormal escalation of fault current is one of the challenging issues of concern. This paper proposes a simple current control topology in collaboration with solid state relay to handle dynamic and transient disturbances without disturbing the power flow within MG.

The voltage and frequency droop control topology is adopted to estimate the AC active and reactive power contribution of islanded MG. Here the load active and reactive power governs the output voltage and frequency as described in (1) and (2). $E = E^* - a \times (Q - Q^*)$….(1) $f = f^* - b \times (P - P^*)$ ….(2)

E and f represents the system operating voltage and frequency respectively. P and Q represent operating load's active and reactive power demands, whereas E* and f* represents the rated voltage and frequency of the isolated system. Likewise P* and Q* are the active and reactive power of the system under no load condition.

The voltage and frequency droop coefficients 'a' and 'b' are further expressed in equation (3) and (4).

$a = \Delta V / 2Q^*$… (3)

$b = \Delta f / P^*$…. (4)

ΔV and Δf introduces the deviation of voltage and frequency under different loading condition respectively. The instantaneous active and reactive power is formulated using the dq components of measured three phase load voltage Vabc and load current Iabc according to Park Transformation.

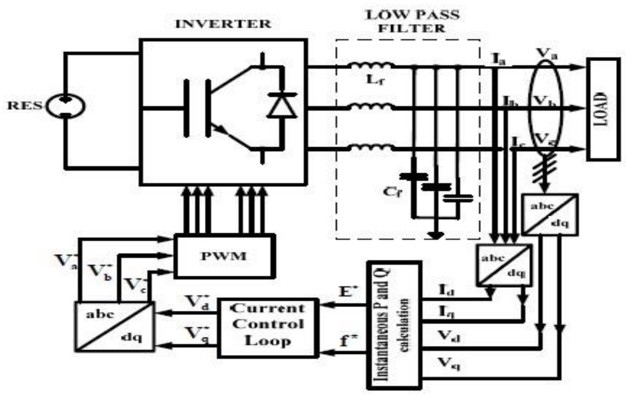


Figure 2 :Overall MG control configuration

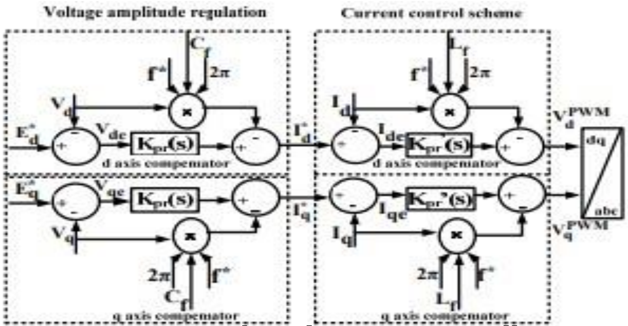


Figure 3 : PR based current controller

Progressing to the next step, Figure 3 depicts the generation of PWM voltage signal which controls the inverter output for distinct loads. In order to create error signals Vde(n) and Vqe(n) at nth sampling instant, the dq components of reference voltage Ed * and Eq * which are generated from voltage droop control is compared to the dq components of actual system voltage Vd(n) and Vq(n) as expressed in (5) and (6).

$$Vde(n)= (Ed^*-Vd(n))\ldots\ldots. (5)$$

$$Vqe(n)=(Eq^*-Vq(n))\ldots\ldots\ldots(6)$$

Since the PWM driving voltage signals are so far developed in synchronously rotating frame, inverse of Park Transformation is further incorporated to acquire the equivalent abc voltage PWM input signal. The control topology sufficiently handles any kind of load diversity in steady state and dynamic state.

IV. SIMULATION RESULTS

The islanded MG with proposed controller is carried out using MATLAB simulation. This presents a dynamic and transient case studies of the islanded MG having different loading arrangement to establish the efficacy of the PR controller. The MG is subjected simultaneously under switching of linear and non linear loads to establish its effectiveness in dynamic state. Whereas symmetrical and unsymmetrical fault conditions are tested to represent the transient state analysis.

A. CASE-I (Dynamic state analysis)

This section shows the waveform of load voltage and current when the islanded MG is tested under switching of variety of loads. Here the MG is at first connected to an first linear load which remains unaltered throughout the simulation. Another linear load after 1 sec is next burdened over the MG model with Further, at 1.2 sec as a non-linear load is switched on following the same manner. The non linear load is produced by connecting a resistive load to an uncontrolled rectifier. The waveform clearly shows the effectiveness of the proposed current control scheme which handles the voltage and current profile without delay thus maintaining a constant voltage even if linear, non-linear loads are simultaneously placed on the MG.

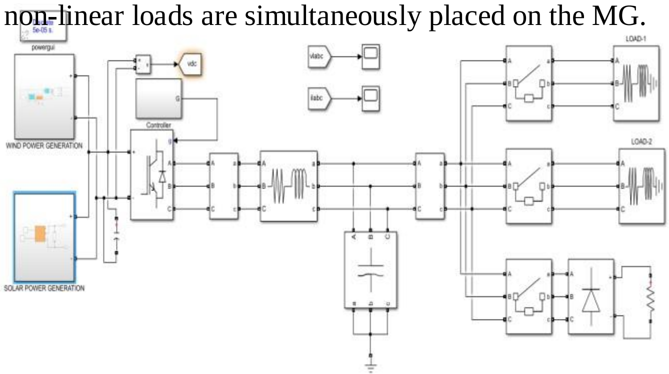


Figure 4: Simulink model in dynamic state

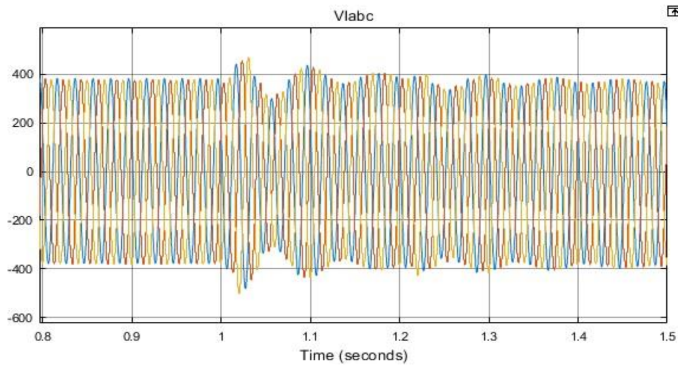


Figure 5 : Voltage waveform when switching of loads takes place

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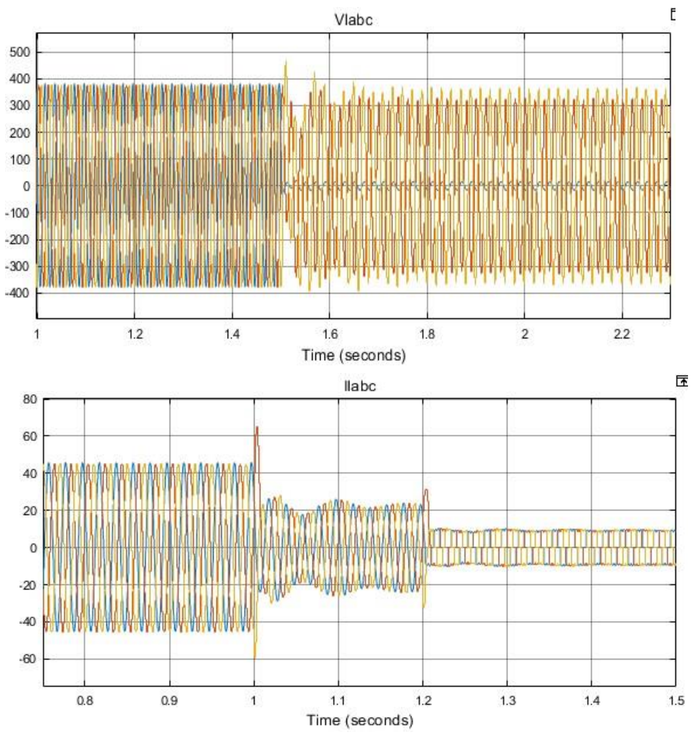

Figure 6 :Current waveform when switching of loads takes place

B. CASE-II (Transient state analysis)

To prove the effectiveness of the solid state relay unit, the MG is tested under both symmetrical and asymmetrical fault condition. The test results are presented in the following section

1) Unsymmetrical fault

The most common unsymmetrical fault of power system i.e. L-G fault is tested in the MG at 1.5 sec according to Fig. 7. As the fault current is quite high comparing to the normal rated current of the system no longer it is allowed to circulate in the circuit. Thus solid state relay interrupts the current immediately to protect all the associated current sensitive components.

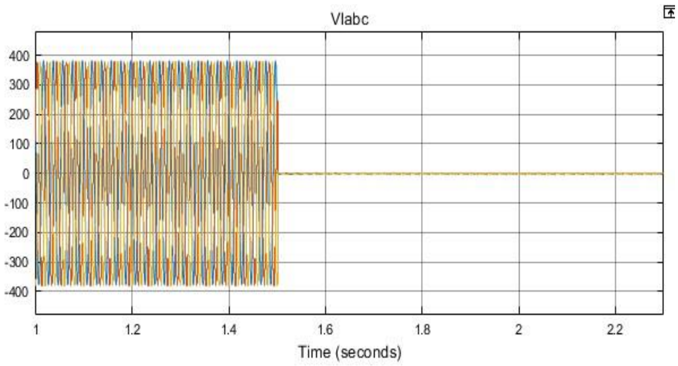

Figure : 11 voltage waveform when L-L-L-G fault takes

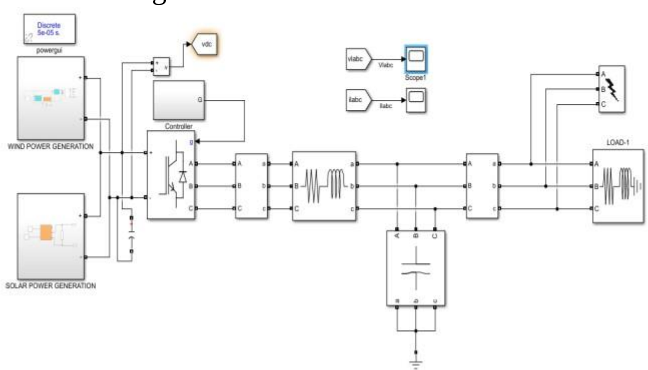

Figure 7: Simulink model in transient state

Figure 9 clearly shows that at 1.5 sec when the L-G fault takes place the solid state relay sends a tripping signal to static switch to isolate the faulted part from the system, thus the current instead of approaching to an abnormal rise, drops down to zero. However, the remaining two phases remain unaltered.

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Figure 8 : voltage waveform when L-G fault takes place

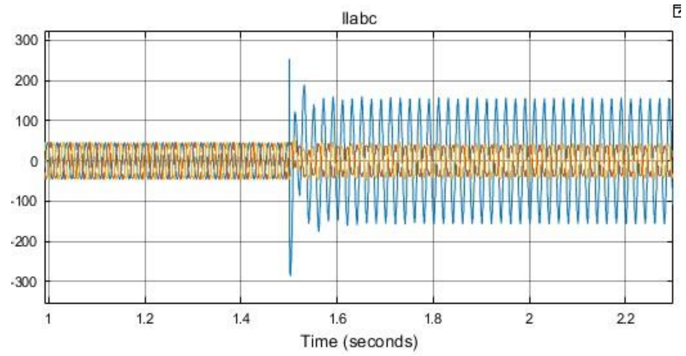

Figure 9 : Current waveform when L-G fault takes place

2) Symmetrical fault Condition

The other type of power system fault ie., symmetrical fault is also tested in this context. Fig. 9 shows the current waveform when the MG is tested under the most severe fault i.e., L-L-L-G fault. Here also it is clearly shown in Fig. 9 that due to the effectiveness of the solid state relay without further delay the faulty section is immediately isolated right after the initiation of the L-L-L-Gfault.

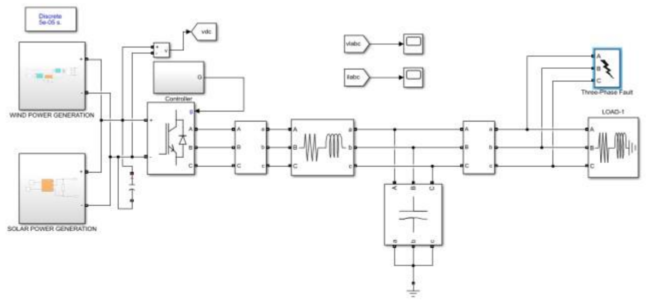

Figure 10: Simulink model in transient state

place

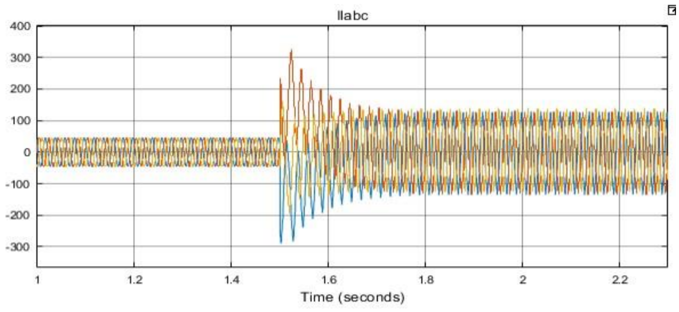

Figure 12: current waveform when L-L L-G fault takes place

3) FFT Analysis

It is clearly visible that the THD of voltage is only 1.14% and the THD of current is only 1.20% when PR controllers are incorporated in current control topology. According to IEEE 1547 standards, for any healthy system, the THD for voltage and current should be less than 5%. Referring to IEEE 1547 standard, the obtained THD% of voltage and current of MG under disturbance is significantly less than their margins. Thus it can be concluded that using this control topology, the overall performance of the system can be much more improved.

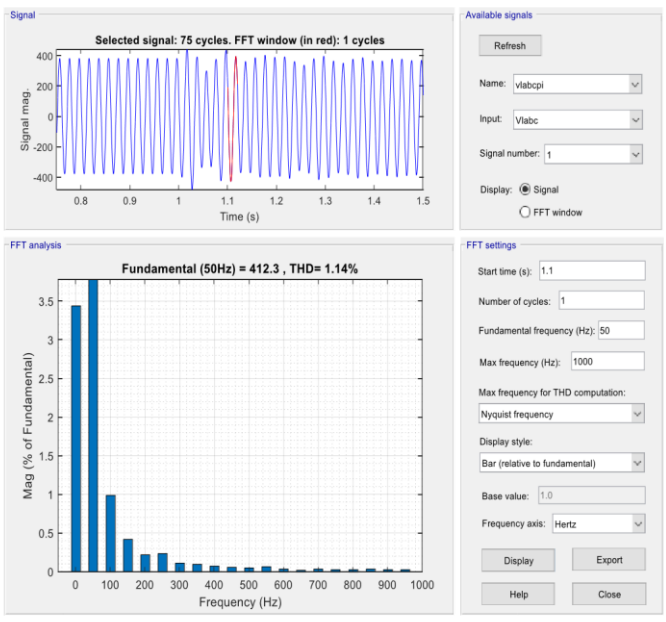

Figure 13: Vabc THD(1.14%)

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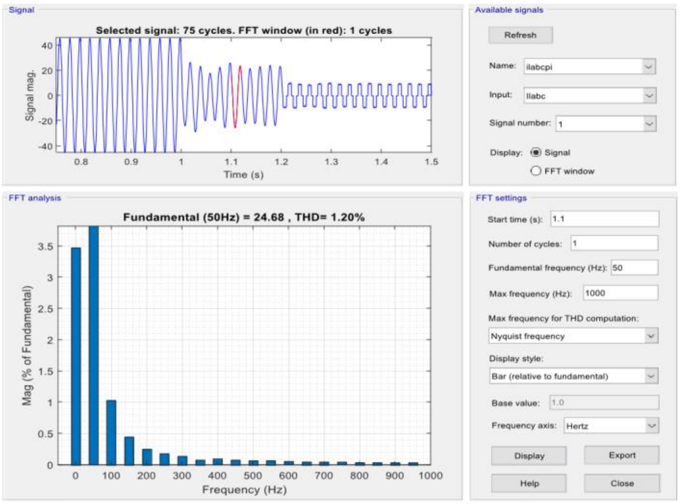
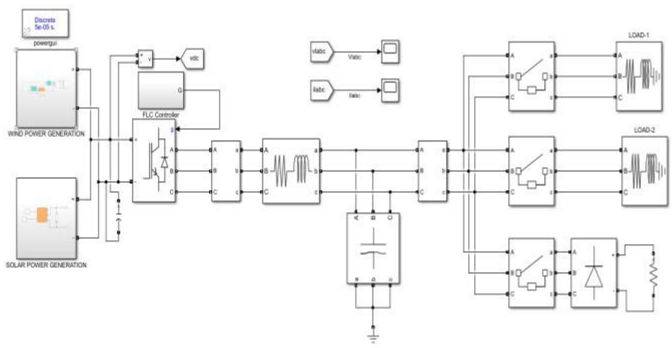


Figure 14: Iabc THD(1.2%)

V. FUZZY LOGIC CONTROLLER SIMULATION RESULTS

The islanded MG with fuzzy logic controller is carried out using MATLAB simulation. To improve the THD of voltage and current fuzzy logic controller is used in place of proportional resonant based current contrlloer. The voltage and current waveforms under dynamic state conditions are obtained as follows



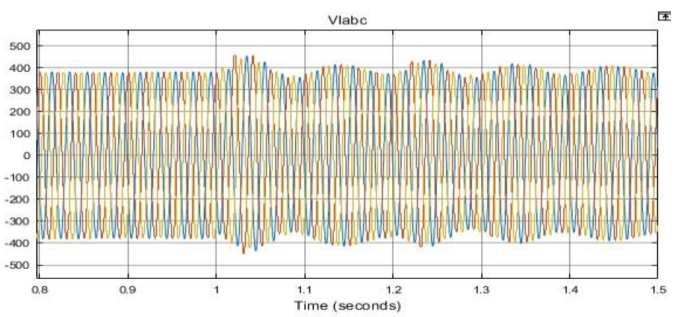


Figure 15 : Voltage waveform when switching of linear and non linear loads takes place

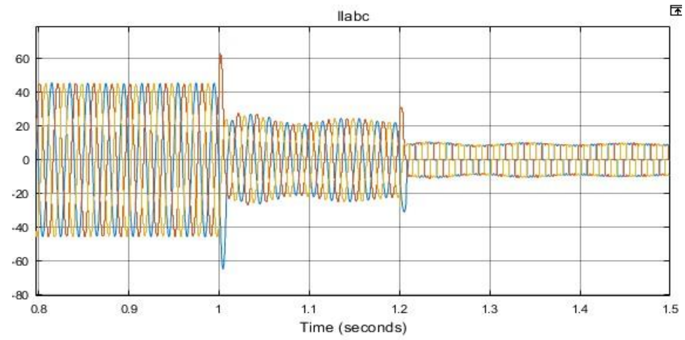


Figure 16 : Voltage waveform when switching of linear and non linear loads takes place

FFT analysis

The THD% of voltage is only 1.05% and the THD% of current is only 0.79% when fuzzy logic controllers are incorporated which is less than result obtained when PR controller is incorporated.

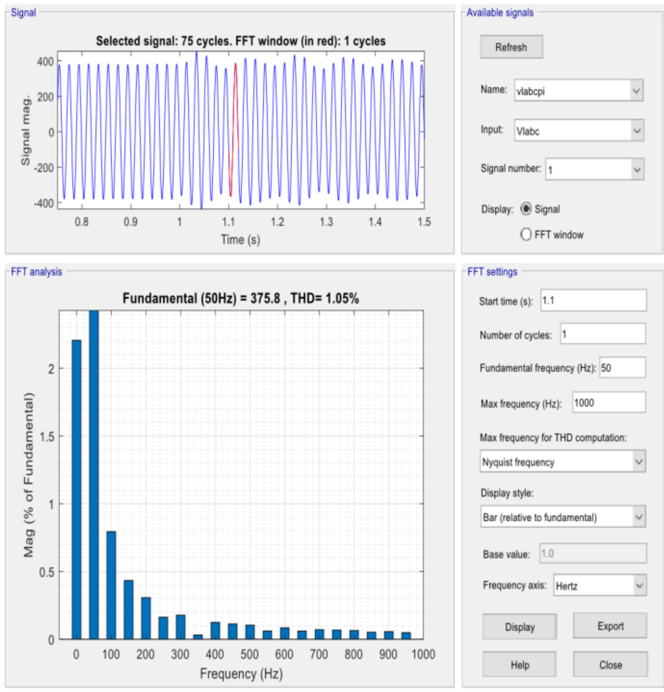


Figure 17 : Vabc THD(1.05%)

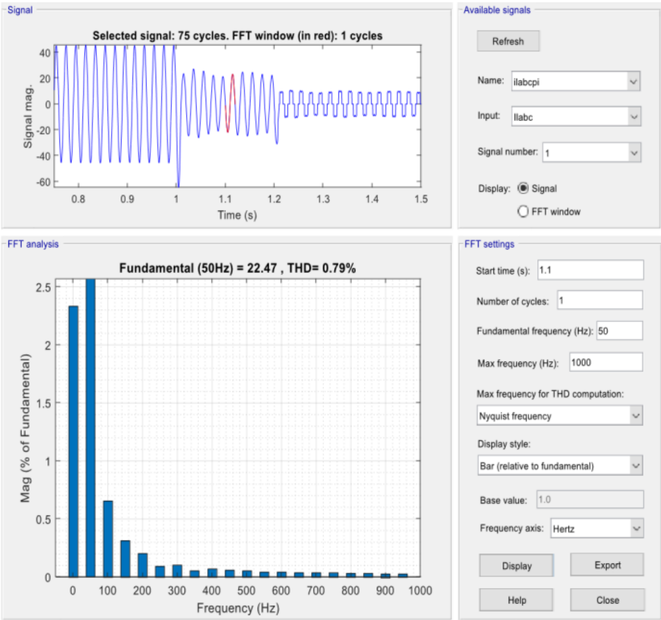


Figure 18 : Iabc THD(0.79%)

Table1- Comparision of proportional resonant and fuzzy logic controller in terms of THD of voltage and current

	PR controller	Fuzzy logic controller
Voltage THD	1.14%	1.05%
Current THD	1.20%	0.79%

VI. CONCLUSION

This paper presents a novel control scheme using a proportional resonant based current controller to handle both the dynamic and transient state of an islanded MG.

The control scheme selectively isolates the faulty section of the MG without hampering the power delivery capability of the RESs as well as handles the voltage and current profile under switching of various types of load.

The simulation results of various case studies establish the effectiveness of the proposed PR controller. THD of voltage and current 1.14% and 1.20% is obtained which is well within the margin(5%) as per IEEE standard.

To improve total harmonic distortion (THD) fuzzy logic controller is incorporated in place of PR controller the results obtained THD of voltage and current is 1.05% and 0.79% which is less than the results obtained in PR controller.

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