VOLTAGE AND FREQUENCY REGULATION WITH SYNCHRONIZATION OF MICRO GRID UNDER ISLANDING OPERATION

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Abstract— The day-by-day increasing demand for energy can create problems for the power distributors, like grid instability and even outages. The necessity of producing more energy combined with the interest in clean technologies yields in an increased development of power distribution systems using renewable energy. In this purview, several types of Distributed Generations (DGs), local loads, storage system and voltage source converter can be connected together to form a small local power generation system called as micro grid (MG). MG can operate in grid connected mode or in islanding mode. The paper discusses islanding control of power electronics interfaced with DG systems in micro grid. Further, a new topology is introduced with zig-zag/star transformer, which reduces the size of battery connected parallel to DC link of the voltage source converter, hence reducing the cost of the system. The proposed topology works well in maintaining phase angle, voltage and frequency of the micro sources in islanded mode as well as in resynchronization when one of the micro sources is off due to fault or unavailability of resources. The proposed topology is verified in MATLAB environment.

Keywords—Distributed generation; load shedding; micro grid; synchronization; voltage source converter (VSC); Zig-zag/star transformer.

I. INTRODUCTION

Power system deregulation, shortage of transmission capacities, discontinuous power supply and the need to reduce green house effect has led to the popularity of distributed generations (DGs) especially in renewable sources. Moreover, power supply to remote areas is still a problem, where as the energy (wind, solar, bio-mass) available in these areas is abundant. Unfortunately as per the statistics of year 2013 the energy generation by these alternate sources is only 12.20% of the total generation (MW). Thus integrating small generating units (micro sources), voltage source converters and storage system to supply local loads, is a very lucrative alternative and this aggregation is called as a micro grid. The micro grid can operate in two modes i.e. grid connected as well as in isolated mode [1]. Moreover, the transition between the two modes should be smooth to minimize any sudden voltage or current change between the local loads and the grid.

A lot of research has been done on isolated operation of distributed system for generating power to local loads [2-4]. The increasing penetration of distributed generation system into the grid requires cheap and integrated control systems. The integration of DGs in parallel with other DGs to form a micro grid and its interconnection with the main grid leads to various problems like, poor voltage regulation, frequency drop and loss of synchronism. The concept of microgrid was introduced by lasseter [5] and its integration with voltage source converter under autonomous and islanding mode was introduced in [6]. A single machine can synchronize with grid using synchronizer, but synchronization of micro grid that operates with multiple DGs and loads cannot be synchronized with traditional synchronizer. Thus authors [7] present a new automatic synchronization method which adopts the network-based coordinated control of multiple DGs. The islanding operation of micro grid is an important issue during grid failure, distorted supply. Thus authors [8] developed an intelligent load shedding and intentional islanding algorithm which improves the performance of the micro grid. When interconnecting the micro grid with the main grid, many authors have developed synchronization algorithms [7-10] considering each micro source as a dc source. In a micro grid maintaining voltage and frequency constant of a micro source is an important issue in addition to synchronization. Thus this paper presents a microgrid comprising of three SEIG driven hydro turbines (micro sources) with a new controller topology which controls (i) voltage and frequency of each micro source (ii) synchronization of micro sources after a fault in one micro source (iii) avoid load shedding condition during fault in any one micro source (iv) reduce rating of the voltage source converter with the help of a zig-zag/star transformer.

II. SYSTEM CONFIGURATION

Micro grid architecture is shown in fig 1. The micro grid is operating in islanded mode. Islanding is a situation where micro grid is disconnected from the main utility but remains energized and continues to supply local

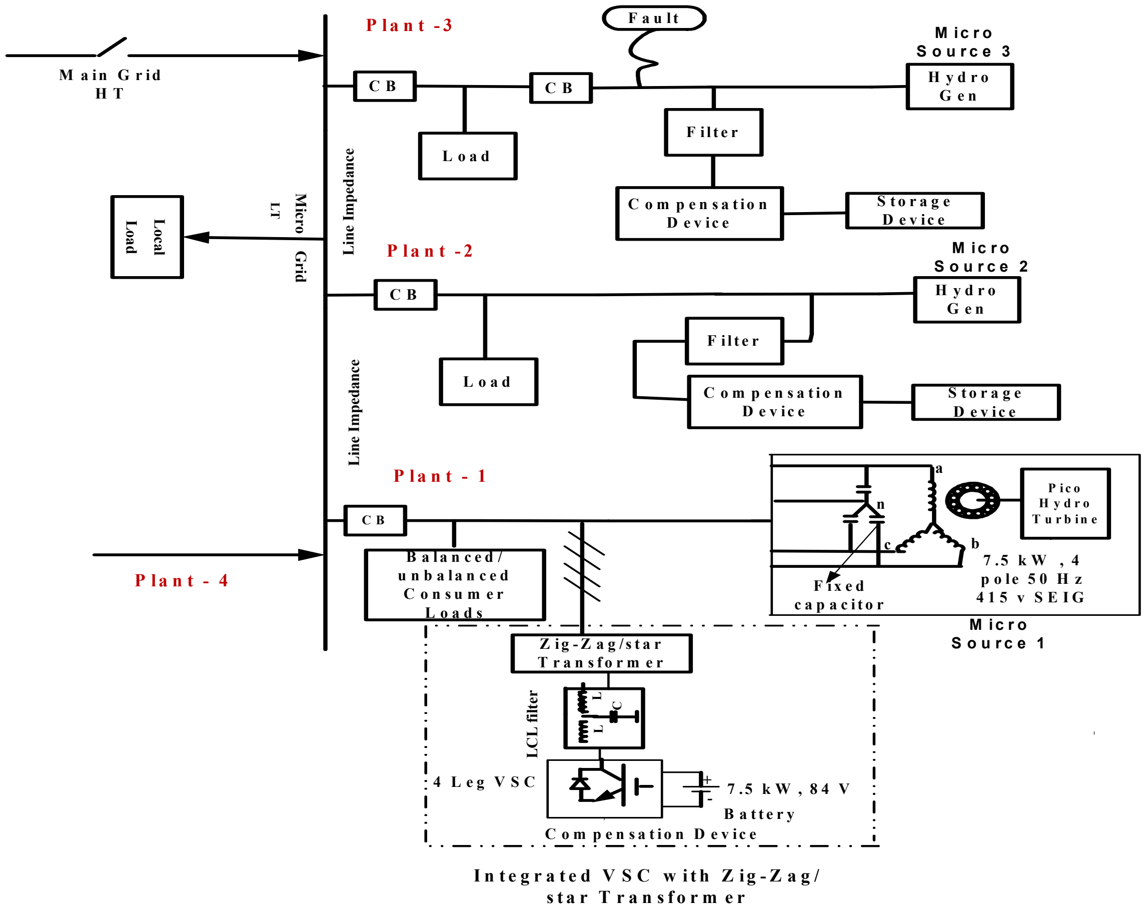


Fig 1: The micro grid with micro sources, loads and controllers

loads. Micro grid can be formed by many numbers of DG systems connected together. This paper considers a micro grid formed by three hydro power plants connected parallel to each other. Each hydro power plant consists of a Self Excited Induction Generator (SEIG) driven by hydro turbine, VSC with battery storage system, zig-zag/star transformer and a second order LCL filter for harmonic elimination. SEIGs have problems of voltage and frequency instability, but due to less maintenance, robust construction, these are preferred in microgrid applications [2-4]. These problems associated with SEIGs are overcome by a proper VF controller. When these SEIGs are connected to form a microgrid, an additional problem of phase angle mismatch also occurs.

The reduced rating VF controller proposed in this paper effectively improves phase angle matching, voltage and frequency instability with an optimally sized battery in a microgrid. The battery size is considerably reduced by employing a zig-zag/star transformer. The proposed controller is also effective when one micro source is shut down due to unavailability of resources or due to fault in line. The faulted micro source is unable to feed its load demand. Due to proper controller action of the remaining micro sources, the load is shared and the voltage and frequency of the system is maintained constant. The controller provides proper phase matching when the outage micro source is reconnected in the system. The performance of the microgrid is investigated in MATLAB environment considering balanced/unbalanced nonlinear loads. The system parameters used for simulation are given in the appendix.

III. DESIGN OF REDUCED RATING VF CONTROLLER

a) Battery sizing

The VF controller comprises of a IGBT BASED voltage source converter with a battery storage system at its dc link. The capital cost of battery storage system is directly proportional to its size and energy storage capacity. In order to reduce the size of battery zig-zag /star connected transformer is used with voltage source converter. Zig-

zag/star transformer is connected in between the point of common coupling (PCC) of SEIG and VSC.
The zig-zag /star connected transformer is used for the neutral current compensation and to adjust the DC link voltage to an optimum level [4]. Each micro source consists of 7.5 kW, 4 poles 415V, 50 Hz, SEIG, with excitation capacitor bank of 5 KVAr and a zig-zag/ star transformer based VF controller
The rating of the zig-zag/star transformer is obtained for 7.5 kW load as:

$$(KVA)_{z\text{-}z} = 0.5[\{6 \times I_L \times (V_L / 3)\} + \{3 \times (I_L) \times (V_L /3)\}] \quad (1)$$

Where $I_L = 14.5$, $V_L = 415$ then $(KVA)_{z\text{-}z} = 9$ KVA.
Zig-zag/star transformer is formed by using three single phase transformer each of 3 kVA. In order to connect VSC to this transformer a set of third winding in each phase is introduced at the secondary of the transformer known as tertiary winding. The voltage rating of this winding is optimized at 26V in order to reduce the battery voltage to 84 V connected at the DC link of VSC. A conventional VSC without zig-zag transformer in [3] requires a battery voltage as high as above 700 V.

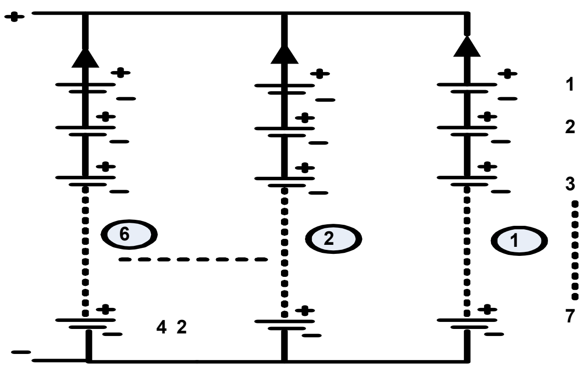


Figure 2: Proposed topology based Series parallel connection of battery for VF controller

The variation in battery voltage of order 84 V to 94 V is considered under charged and discharged condition. Considering the ability of the proposed system to supply the maximum load of 7.5 kW for 10 hours peak capacity, the design storage capacity of battery is taken as 75 kWh. The commercially available battery consists of cell of 12 V. The capacity of each cell is 150 Ah. To achieve dc voltage of 84 V through series connected cells of 12 V, the battery should have (84 / 12) = 7 numbers of cell in series. The storage capacity of the battery is 150 Ah. The total ampere hours required is [(7.5 × 10) / 84] = 892.8 Ah, thus the number of such sets required to be connected in parallel would be (892.8 Ah / 150 Ah) = 6. Thus a battery bank set of 7 series and 6 parallel combinations are required. The conventional VSC requires 40% additional series connected battery banks.

b) *Design of Voltage Source Converter*

The voltage rating (V_{rs}) of each IGBT can be calculated as

$$V_{rs} = V_{dc} + V_d \quad (2)$$
$$= 84 + 8.4 = 92.4 \text{ V}$$

Where V_d is 10% overshoot in the DC link voltage under varying load condition. The rated current which flows through the three-leg VSC is I_{sr}. The peak value of the current is $\sqrt{2} \times I_{sr}$. The I_{sr} is the required current flowing through VSC, considering the safety factor of 1.25, the maximum device current can be calculated as

I_{sr} = 1.25 (5% of peak value of rated current + peak value of rated current) (3)

$$= 1.25(5.51 + 110) = 144.3 \text{ A}$$

The commercial available devices higher than these values are 100 V and 150 A which can be used. These ratings are much lower than conventional VSC system used in [2, 11] which requires IGBT of rating 1200Vand 50 A.

IV. CONTROL STRATEGY OF REDUCED RATING VF CONTROLLER

Voltage frequency regulation & Synchronization

The implemented control strategy is shown in figure 3. According to the power balance principle, the unbalance power between micro source and load cause voltage and frequency deviation. Therefore, battery with voltage source converter (VSC)-based voltage and frequency (VF) controller is utilized to compensate the unbalance power and then adjust the system frequency and voltage within a stable range. Figure 2 shows the VF control strategy for the proposed micro grid configuration. The output power of battery is controlled by adjusting reference source currents (i^*_{sa}, i^*_{sb}, i^*_{sc}). Reference source currents are divided into active power component (i^*_{sapp}, i^*_{sbpp}, i^*_{scpp}) for regulating the frequency and reactive power component (i^*_{saqq}, i^*_{sbqq}, i^*_{scqq}) for regulating the voltage as shown in Figure 4.

To estimate the active component of the reference source current, the output of the PI frequency controller (I^*_{amd}) is compared with the rated generator current (I_{gene}) and the difference is considered as an amplitude of in-phase component of the reference current (i^*_{spp}).

The synchronization of micro grid is quite different as compared with the synchronization of single machine because micro grid consists of many DGs, including unpredictable renewable energy resources and varying electrical loads [7]. In parallel operation of AC generators, it is necessary to match phase angle, frequency and voltage difference as close as possible.

These conditions are referred as synchronizing criteria. Thus in a micro grid system synchronizing conditions should be fulfill by each generating units then only these unit are connected in parallel with varying load

The synchronizing angle θ as shown in Figure 5 obtained from phase locked loop (PLL) is used to generate unity vector template. This angle (θ) can be grid angle when working in grid connected mode, but in the islanded operation of micro grid this angle (θ) is obtained from any reference (master) plant and rest is acting like slave plant. Here plant one is considered as master plant and rest two plants are considered as slave plant. The unit templates are obtained as:

$U_{va}=\sin(\theta)$ (4)

$U_{vb}=\sin(\theta-2\Pi/3)$ (5)

$U_{vc}=\sin(\theta+2\Pi/3)$ (6)

The multiplication of i^*_{spp} with unit templates (U_{va}, U_{vb}, U_{vc}) yield the in-phase components of the reference source current (i^*_{sapp}, i^*_{sbpp}, i^*_{scpp}). To generate the reactive component of the reference source current, another set of quadrature templates (Q_a, Q_b, Q_c) are derived from in-phase templates which are 90^0 leading from the corresponding voltages. The multiplication of these templates with the output of PI terminal voltage controller (i^*_{sqq}) gives the reactive component of the reference source current (i^*_{saqq}, i^*_{sbqq}, i^*_{scqq}). The s um of active and reactive component yields the total reference current (i^*_{sa}, i^*_{sb}, i^*_{sc}). These reference currents are then compared with the sensed generator currents (I_{ga} , I_{gb} , I_{gc}). The difference of these signals (error) is given to the hysteresis controller. The hysteresis controller generates the pulses for the IGBTs in a 3-leg voltage source converter

V. PERFORMANCE EVALUATION

Micro grid in the proposed configuration consist of SEIGs, zig-zag/star transformer, LCL filter, VF controller, distributed line impedance, three phase non-linear load and passive RC filter are modeled in MATLAB environment shown in Figure 6. The performance of micro grid with the proposed reduced rating VF controller operating under islanded mode and after failure of one micro source is investigated through simulations. The subscript '1, 2, 3' is used for plant 1, plant 2and plant 3. The description of the waveform is as follows:

V_{gabc} (3-ϕ generator voltage), i_{gabc} (3-ϕ generator current), i_{Labc} (3-ϕ balanced/unbalanced load), V_t (terminal voltage), V_{dc} (DC link voltage), I_n (neutral current), I_{batt} (battery current), f (frequency). First the micro source builds up its no load voltage with the help of the capacitor bank, and a steady state voltage is obtained near 0.4 s. During this interval since the SEIGs are at no-load, the system frequency is above 50 Hz. Later on at 0.8 s controller is turned on and the terminal voltage and frequency are regulated in subsequent 10 cycles. V_{gabc} (3-ϕ generator voltage), i_{gabc} (3-ϕ generator current), i_{Labc} (3-ϕ balanced/unbalanced load), V_t (terminal voltage), V_{dc} (DC link voltage), I_n (neutral current), I_{batt} (battery current), f (frequency). First the micro source builds up its no load voltage with the help of the capacitor bank, and a steady state voltage is obtained near 0.4 s. During this interval since the SEIGs are at no-load, the system frequency is above 50 Hz. Later on at 0.8 s controller is turned on and the terminal voltage and frequency are regulated in subsequent 10 cycles.

(i) Islanding mode

Control of micro source is critical in islanded mode as each micro source has limited capability. If the load connected is much greater than generated power of the micro grid, load shedding of non-critical loads is unavoidable. In this configuration load 3 is considered as critical load. The performance of VF controller for micro grid under balanced/unbalanced non-linear load is shown in Figure 7. Before the application of consumer load, the battery is charged by the generated active power of each SEIG. Three single phase non-linear loads are applied at 1 s. Between 1.1-1.2 s one phase is disconnected and during 1.2-1.3 s another phase is disconnected hence load becomes unbalanced, as shown in i_{Labc}. The unbalance in load current results in charging and discharging of battery (I_{batt}). Hence the effectiveness of the reduced rating VF controller can be observed under unbalanced conditions.

(ii) Failure of one micro source in islanding mode:

Between 1.4 – 1.5 s micro source '3' is cut off from rest of the system due to fault. Since the load connected to this micro source is critical, it has to be shared by the remaining two plants. This results in discharging of batteries 1 and 2. After the fault clearing micro source has to be reconnected to the system. Under such condition phase of the three sources should be matched for reconnection. The case is similar to grid connection. Fig 8 (a) shows the disconnected micro source V_{gabc3}, the remaining micro sources $V_{gabc\ 1,\ 2}$. V_g (1 & 3) shows the overlapping of a connected and the disconnected micro source. It can be observed that the disconnected micro source is effectively resynchronized after 7.5 cycles, after the fault clearing at 1.5 secs. The phase angle synchronization before the fault and resynchronization of angles after the fault is shown in fig. 8 (b). It can be observed that the proposed reduced rating VF controller,

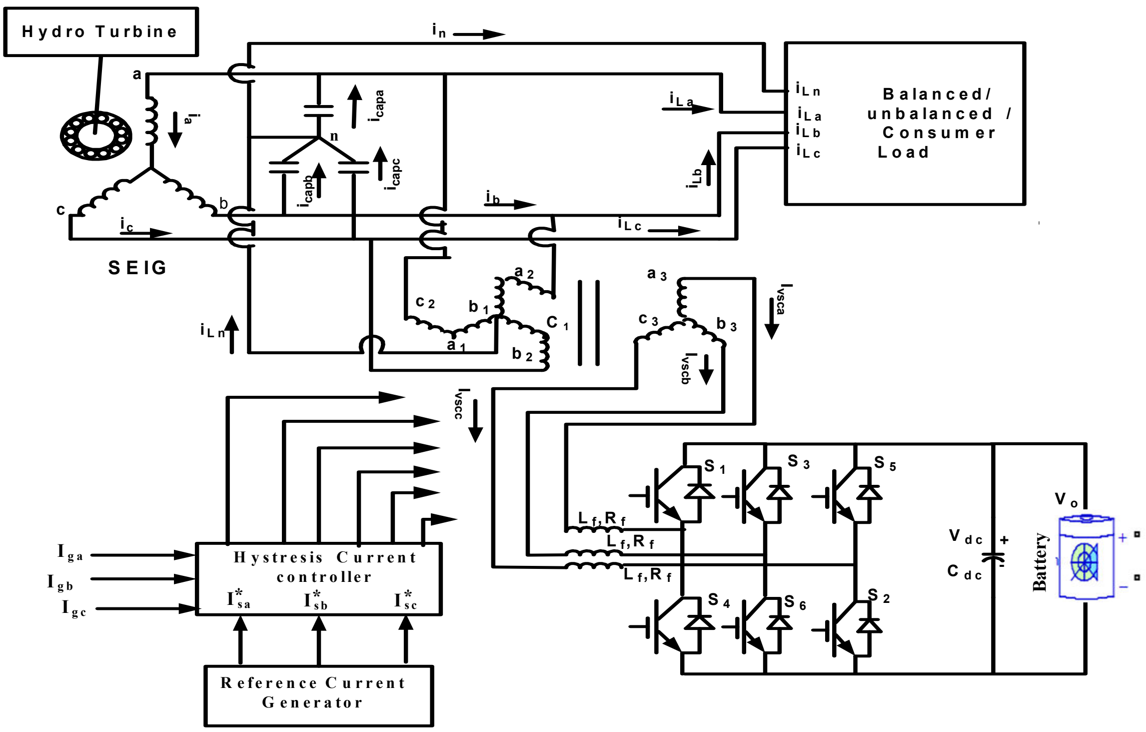


Fig 3: Schematic diagram of plant ‘1’ with its control scheme

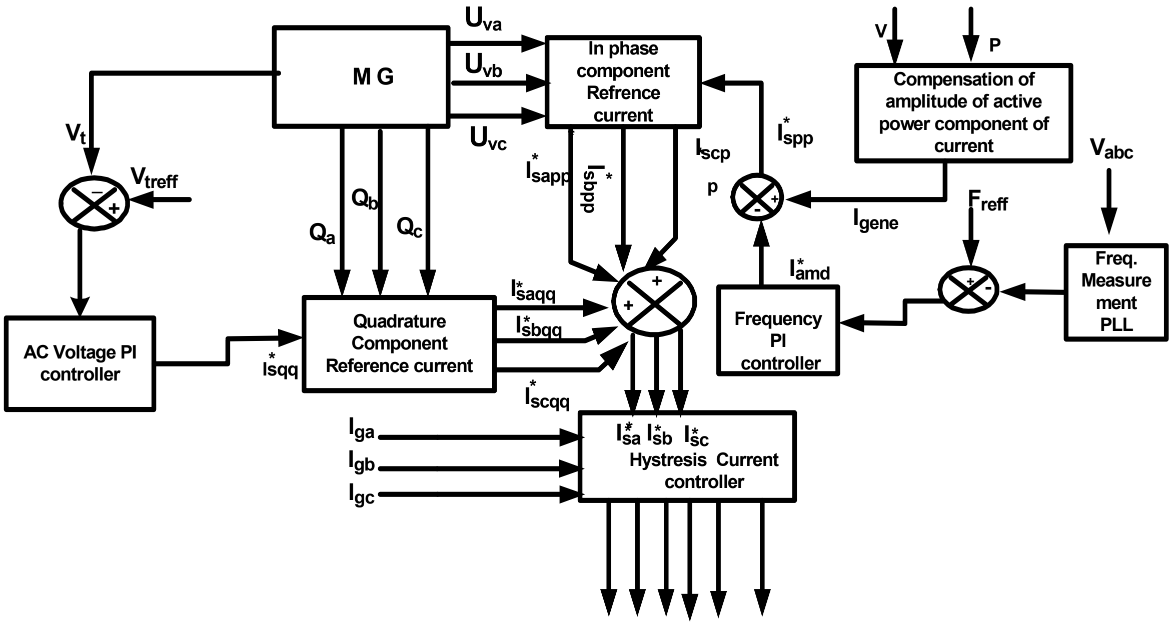


Fig 4: Detailed control scheme of plant ‘1’

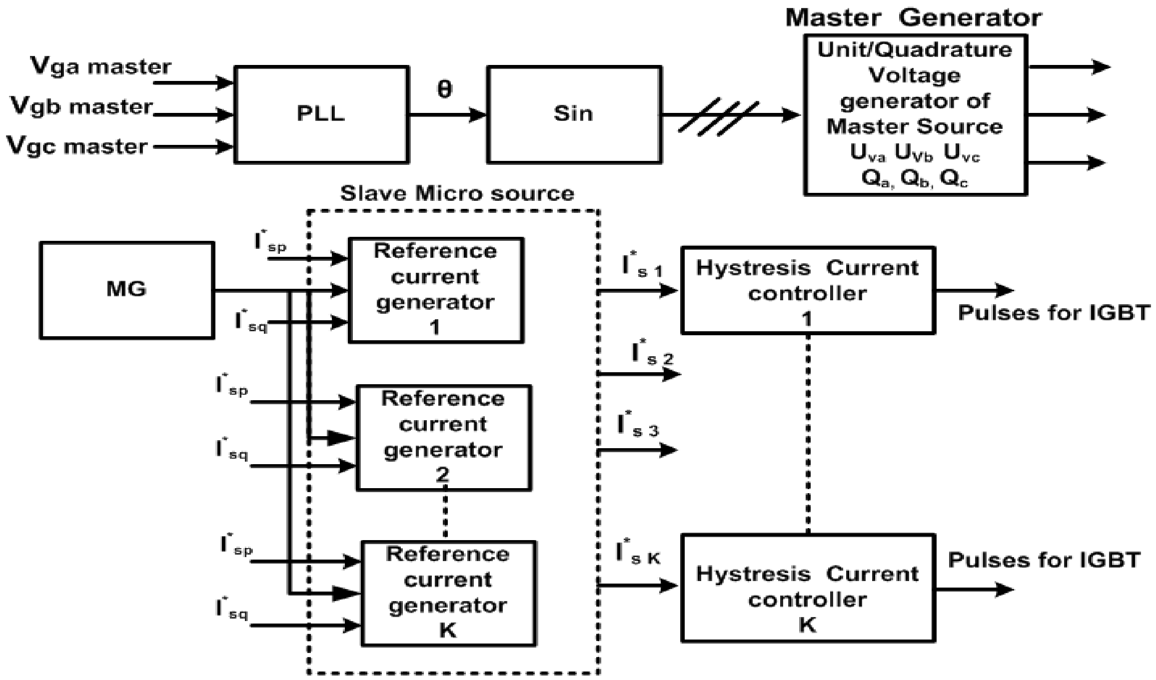


Fig 5: Synchronization scheme of micro grid

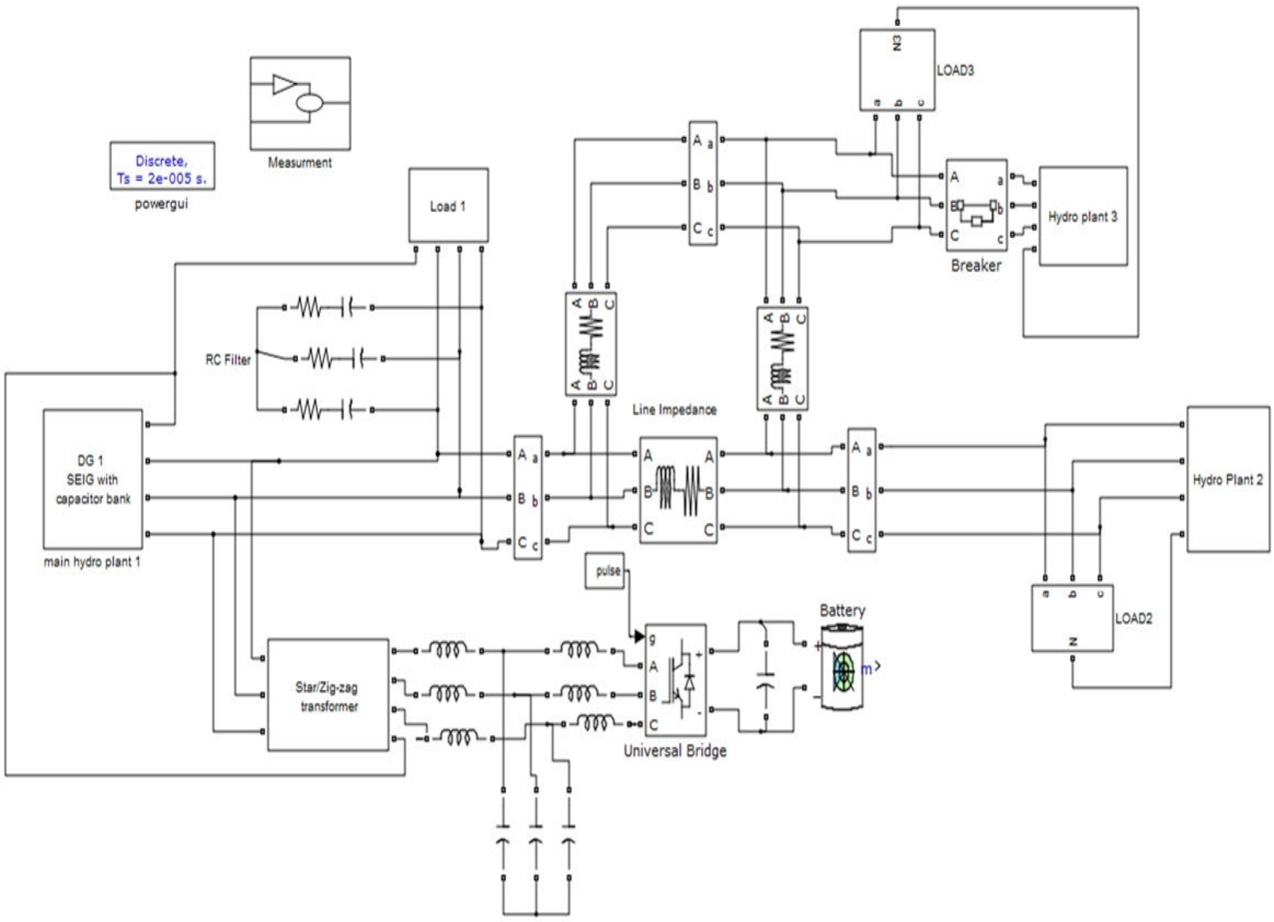
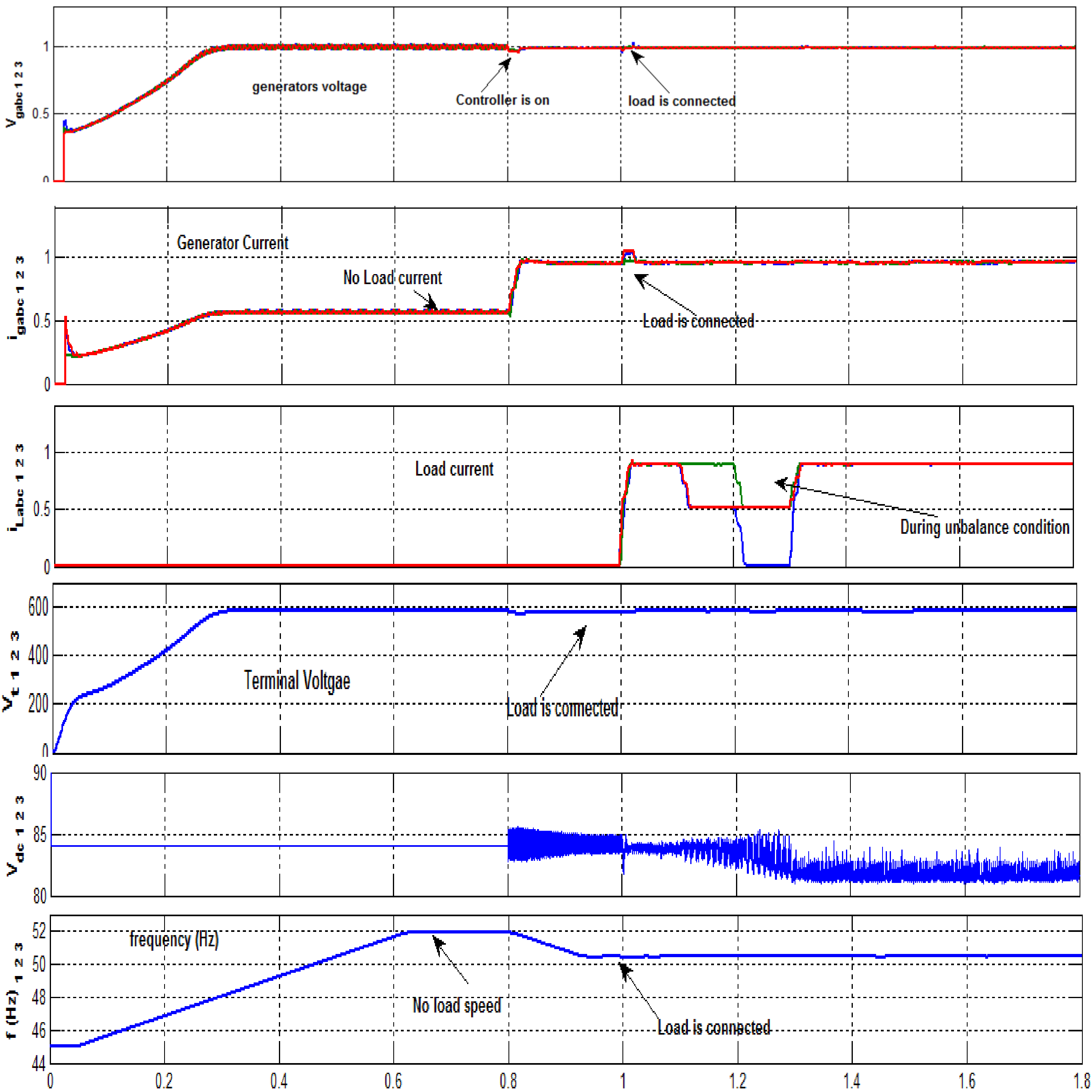


Fig 6: Simulink model of considered system

in addition to voltage frequency regulation, effectively resynchronizes the micro sources.

VI. CONCLUSION

The proposed reduced rating VF controller for micro sources in the microgrid with zig-zag/star topology has been successfully demonstrated through simulation results. The scheme has been shown working satisfactorily for sharing of loads during load perturbations and failure of one micro source in islanded mode. The transients arising from switching of loads or micro sources are mitigated in few cycles and not passed to other micro sources. The proposed scheme in islanded mode ensures that the micro sources (slave) can be effectively synchronized to a master micro source maintaining synchronizing criteria. The scheme is simple, fast sassily implementable for of micro grid in grid connected and islanded mode. The scheme inherently is capable of improving the power quality of micro grid



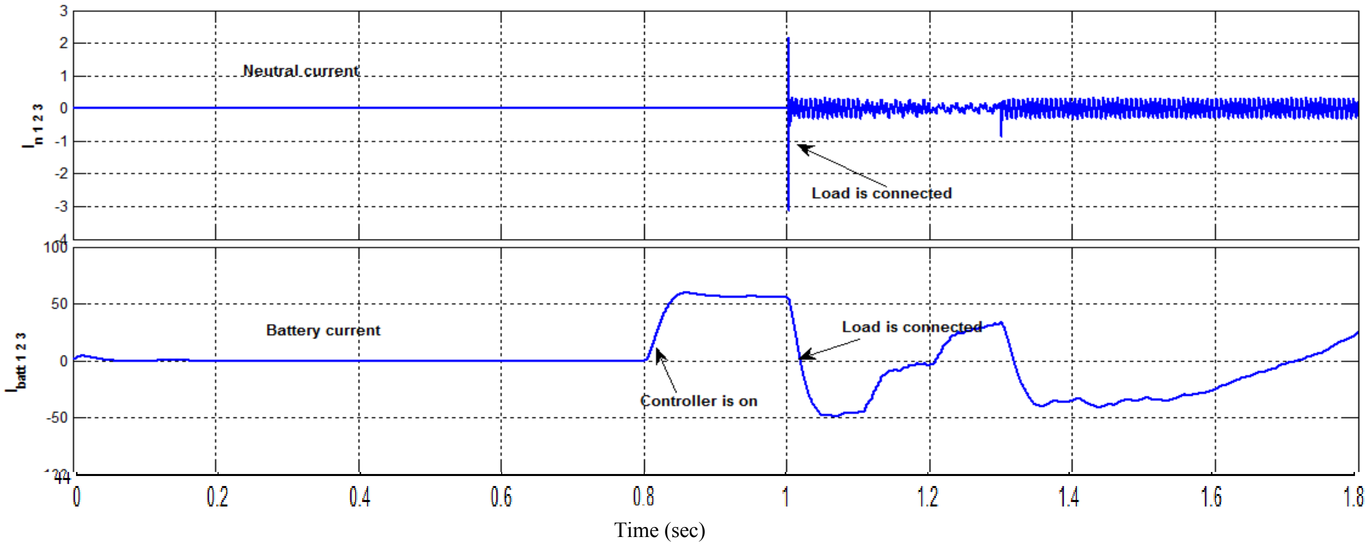
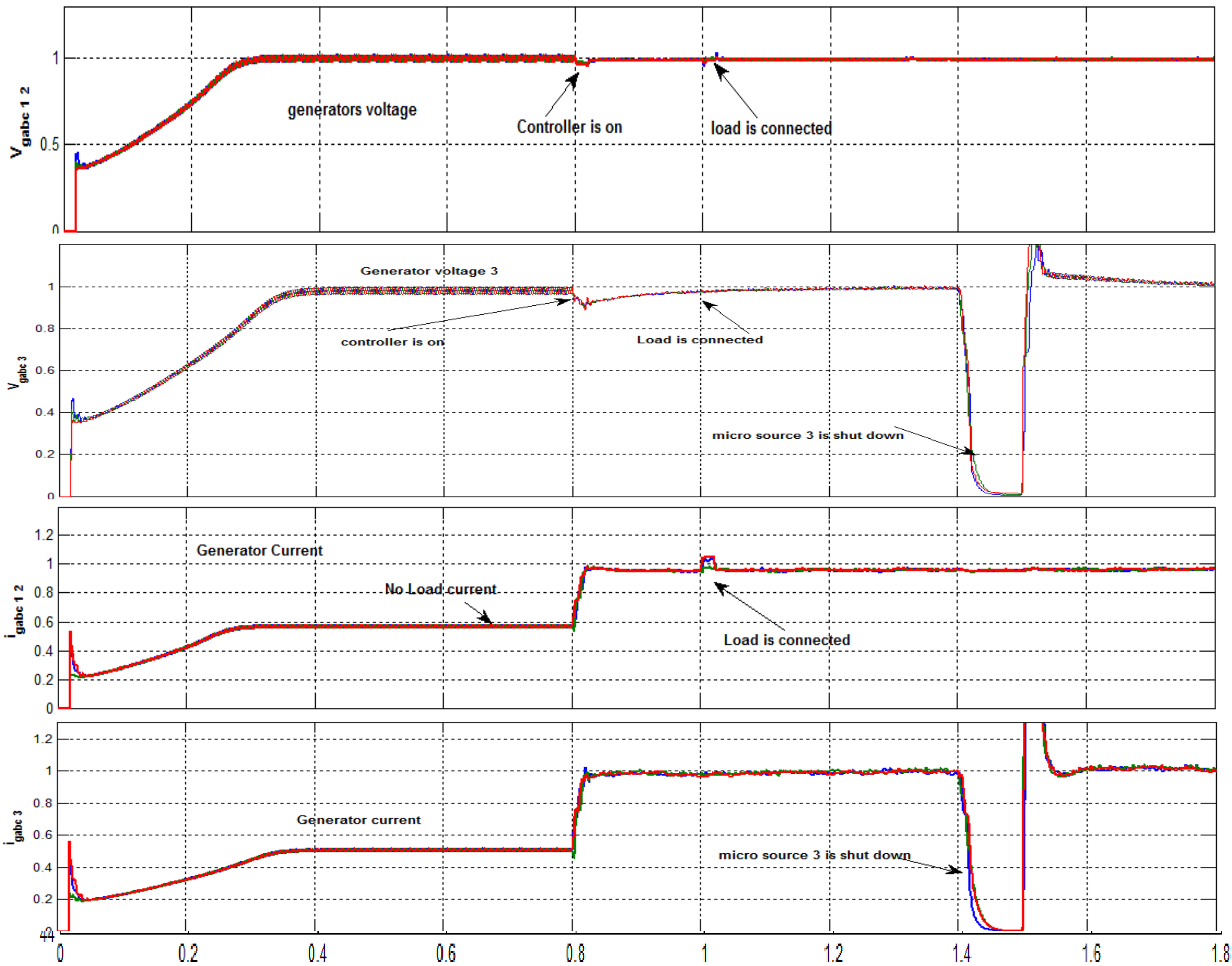


Fig 7: Waveform of micro grid during islanded mode



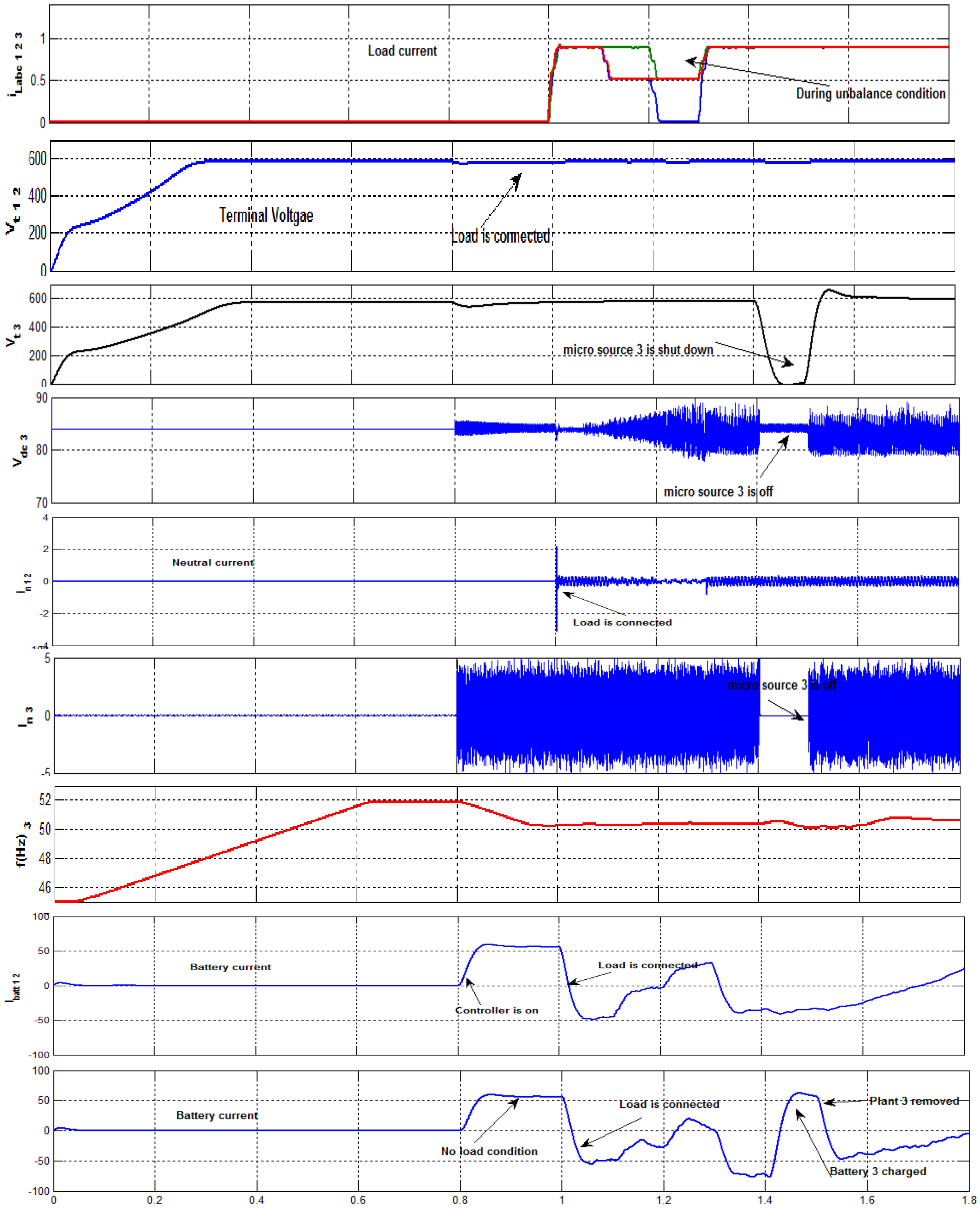


Fig 8 (a): Waveform of micro grid when one micro source is off

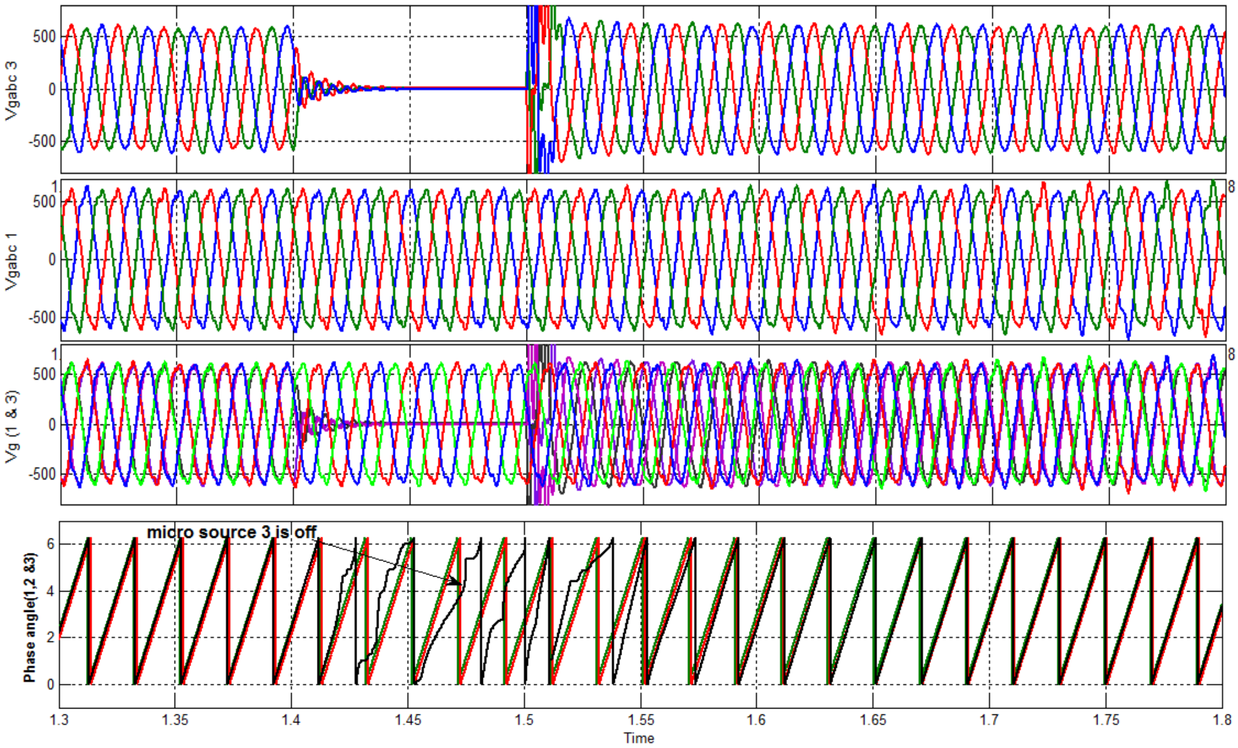


Fig 8 (b): Resynchronization of micro source 3 after the fault

APPENDEX

TABLE 1. Parameters of the considered system

Micro source 1,2,3	7.5 kW, 415 V, 50 Hz, 4 pole
LCL filter	2 mH, 20µF, 0.5mH
Zig-zag/Star transformer (each)	3 KVA, 26 V/140 V/140 V
Line impedance	0.1 Ω, 0.02 mH
DC link voltage	84 V
Non-linear load (each)	2.5 kW, 100 µF, 8 mH at DC end of single phase diode rectifier
Passive filter (R, C)	2 Ω, 15 µF
Converter rating	100 V, 150 A

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