A Reliable Micro-grid with Seamless Transition between Grid Connected and Islanded Mode for Residential Community with Enhanced Power Quality

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***Abstract*—This paper presents a reliable micro-grid for residential community with modified control techniques to achieve enhanced operation during grid connected, islanded and re-synchronization mode. The proposed micro-grid is a combination of solar photo-voltaic (PV), battery storage system and locally distributed DG systems with residential local loads. A modified power control technique is developed such that, local load reactive power demand, harmonic currents and load unbalance is compensated by respective residential local DG. However, active power demand of all local residential load is shared between the micro-grid and respective local DG. This control technique also achieves constant active power loading on the micro-grid by supporting additional active power local load demand of respective residential DG. Hence, proposed modified power control technique achieves transient free operation of the micro-grid during residential load disturbances. An additional modified control technique is also developed to achieve seamless transition of micro-grid between grid connected mode and islanded mode. The dynamic performance of this micro-grid during grid connected, islanded and re-synchronization mode under linear and non-linear load variations is verified using real time simulator (RTS).**

***Index Terms*—Distributed Generation, Micro-grid, Power Quality, Islanded Mode, Grid connected mode, re-synchronization.**

I. INTRODUCTION

CONSIDERING today's worldwide energy crises and global warming issues, power generation using renewable energy sources (RES) are gaining more importance in order to provide continuous and reliable power supply to all distributed local loads. Distributed generation (DG) units equipped with RES providing local distributed load demands forms a structure of micro-grid [1]. This micro-grid can operate either in grid connected mode or in islanded/standalone mode. In a micro-grid, battery energy storage system (BES) is required for energy balancing in the system, especially when it is operating in islanded/standalone mode. Efficient utilisation of local DG units can be achieved by operating all DG's as constant power sources during grid connected mode of operation of micro-grid. In this case grid will maintain the micro-grid voltage [2], [3].

Some of the major challenging issues for smooth operation of the micro-grid are active power load sharing between DG's, harmonics compensation, unbalanced load compensation, reactive power compensation and transition from grid connected mode to islanded mode and vice versa [4], [5]. In literature different control schemes are presented to handle the afore said issues.

Control techniques presented for active and reactive power load sharing between DG's in the micro-grid are divided into two categories as decentralised control (without communication) and centralised control (with communication) [6], [7]. In decentralised control, droop method is used for load sharing between DG's in the micro-grid. It has became very popular due to plug and play type of operation of DG. In this method the active and reactive power sharing is based on their droop constant [8]. A virtual output impedance is incorporated in the droop method in order to achieve accurate active and reactive power sharing between DG's [9], [10]. The disadvantages of basic droop method is variation in voltage and frequency from nominal values at other than rated load conditions. In order to overcome this issue, Hierarchical control of droop method is presented in [11], [12] which comes under the category of centralised control with communication.

In centralised control, master-slave method and average power sharing method is used for active and reactive power sharing in the micro-grid [13]–[15]. Here, master DG should have high power rating [16]. The disturbances occurred in the micro-grid are handled by the master DG (i.e total transients are handled by the master DG). The major disadvantages of this method are the micro-grid is to be shutdown when master DG fails and all transients in micro-grid are handled by the master DG, therefore the burden on the single DG is high [16]. In [17], authors proposed hybrid load sharing method by combining droop and master-slave methods. Here, the DG's which are operated using droop method will act as master DG's and all other DG's are slaves. With this technique, the disadvantages of master-slave and droop method are overcome

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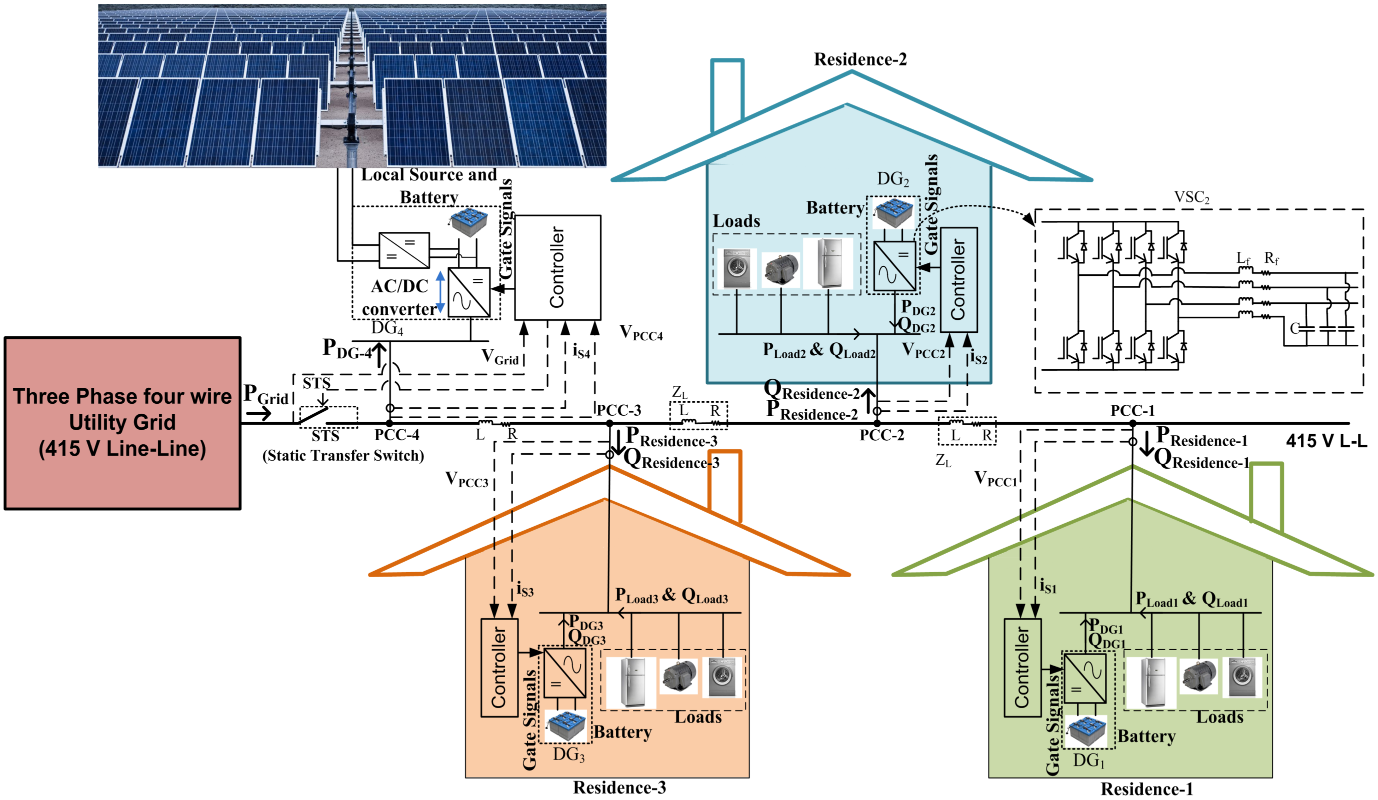

Fig. 1. Schematic representation of proposed grid connected micro-grid.

partially.

The non-linear loads demand harmonic currents in the micro-grid, which leads to distortion in micro-grid voltage. In [18], the harmonics are shared by incorporating active compensation in the controller of DG's. While in, [19], [20] harmonics are shared by adding additional loops in the droop controller of DG's. In the micro-grid, unbalanced loads will cause unbalance in the terminal voltages [21]. In [22], [23] the load unbalance current is shared between DG's without effecting its output voltage.

For seamless transition between grid connected and islanded mode,the additional converter is used as dispatch unit (DU) in [24]. Two PLLs are used in [25] for smooth transition between the modes of operation by minimizing the error between the phases of the PLL. In [26], a synchronizing DG is used for smooth transition during reconnection of micro-grid to the main grid. With the help of synchronizing DG the micro-grid instantaneous phase, frequency and instantaneous voltage is synchronized with the utility grid before reconnection. By this the transients in the system is avoided during transition from islanded mode to grid connected mode. In [27], Linear Quadratic Regulator theory based bumpless transfer scheme is used to achieve smooth transition between the islanded mode and grid connected mode.

This paper proposes, a micro-grid and its control technique to provide reliable power supply to a residential community with enhanced power quality and to achieve smooth operation of micro-grid under grid connected mode and islanded mode. However, the specific challenging issues need to be considered in order to achieve aforesaid objective are: active power load sharing between DG's, reactive power compensation, harmonics compensation, unbalanced load compensation and seamless transition of micro-grid from grid connected mode to islanded mode and re-synchronization to grid. Therefore, the proposed micro-grid control technique is designed to resolve all these necessary issues and achieve smooth operation. The major contributions of this paper are

1) Developed a modified power control technique to achieve following objectives
    - Constant active power loading on the micro-grid from residential local loads, independent of local load variations. Therefore the frequency of the system will not be affected under dynamic load variations.
    - The entire reactive power demand from the local load is compensated by the respective local DG. Therefore, the system bus voltage is unaffected even under reactive power load variation.
    - The unbalance current and harmonics current demanded by the local residential loads are compensated by the respective local DG, in order to avoid micro-grid voltage distortion. Therefore, the proposed micro-grid is free from power quality related issues caused due to unbalanced and harmonics load current demand under both grid connected and islanded mode.
    - In micro-grid the load disturbances are taken care by respective local DGs. Hence, the micro-grid is transient free from the local load disturbances occurred

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in each residence.

2) Developed a control technique for smooth transition from grid connected mode to islanded mode and re-synchronisation to grid.

The micro-grid achieves following advantages, with the proposed control technique of the DG's

i) The dynamic response of system is increased with the proposed control of micro-grid during load disturbances.
ii) The transition from grid connected mode to islanded mode and re-synchronisation to grid is achieved smoothly without affecting the micro-grid voltage during transition period.
iii) The stability of the proposed micro-grid is increased due to transient free operation during the local load disturbances occurred in the residences.
iv) In micro-grid only the active power sharing is done between DGs and the utility grid. If reactive power, harmonics and unbalanced currents are shared between the DGs and utility grid then the micro-grid voltage will be affected. To avoid aforesaid issue, the reactive power, harmonics and unbalanced currents demanded by the local residential loads are compensated by the respective local DG with the help of modified power control technique.

II. SYSTEM CONFIGURATION

The schematic in Fig. 1 represents the proposed micro-grid for residential community. The micro-grid is interconnected to the main grid through the static transfer switch (STS). The STS is controlled by DG_4 controller. Under healthy condition of the main grid, micro-grid is operated in grid connected mode. However during faulty conditions micro-grid is isolated from the main grid by opening the STS. When the fault is cleared islanded micro-grid is re-synchronised to the main grid by operating STS. In micro-grid each residence (residence-1, residence-2 and residence-3) comprises of local DG's (DG_1, DG_2 and DG_3) and local loads. Each DG (DG_1, DG_2, DG_3 and DG_4) in the micro-grid is a voltage source converter (VSC) along with low pass filter L_f, R_f and C at it's ac output side. In DG_1, DG_2 and DG_3, the dc side of VSC is connected with Battery storage system. In DG_4, the dc side of VSC is connected with solar PV and Battery storage system. R and L are equivalent line resistance and inductance.

III. CONTROLLER DESIGN

The control technique of proposed micro-grid is designed such that, it can be operated in grid connected mode, islanded mode and re-synchronisation for grid connected mode. In grid connected mode all the DG's will connect as a constant power sources, here the micro-grid voltage is maintained by the main grid [28]. If any fault occurred in the main grid, then the micro-grid is disconnected from the main grid and operate in islanded mode.

A. Modified power Control technique for DG_1, DG_2 and DG_3

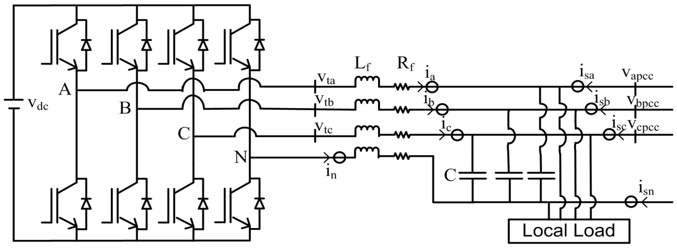

Fig. 2. Schematic of VSC of DG_1, DG_2, DG_3 and DG_4.

A modified power control technique is developed for local residential DG's (DG_1, DG_2 and DG_3) in order to achieve:

1) Transient free micro-grid from the local disturbances occurred in the residences.
2) Constant loading on micro-grid from the residences even under local load variations.
3) Reactive power compensation, local unbalanced load compensation and harmonics compensation of local non-linear load.

Its realization is mainly depends on capability of battery energy storage, this is the limitation for this technique. In this control technique, the residential DG's are controlled by taking feedback signals as, PCC voltage of respective DG's, current supplied by micro-grid to the respective residence. The local DG's are controlled in such a way that respective residence should absorb constant reference active power from the micro-grid irrespective of disturbances. In order to achieve, constant active power loading, reactive power reference is assumed to zero and for supply balance current the neutral current is assumed to zero.

The reference active power (P_{ref1}, P_{ref2} and P_{ref3}) absorbed by the local residential loads from the micro-grid is estimated using pre-calculated average load demand of residential local loads(P_{avg1}, P_{avg2} and P_{avg3}).

$$P_{ref} = P_{avg} \tag{1}$$

To overcome the limitation of modified power control technique, the selected battery capacity should be 150% of average load demand of residential local loads, by this it is possible to simplify the complexity in control.

1) Mathematical modelling of power control: Applying KVL in Fig. 2, the terminal voltage equation at the output side of VSC is,

$$\vec{v}_t = R_f\vec{i} + L_f\frac{d\vec{i}}{dt} + \vec{v}_{pcc} \tag{2}$$

$$L_f\frac{d\vec{i}}{dt} = \vec{v}_t - R_f\vec{i} - \vec{v}_{pcc} \tag{3}$$

In order to achieve synchronisation, instantaneous phase angle of the micro-grid is estimated using synchronous reference frame (SRF) Phase lock loop (PLL). This phase angle is used for park's transformation and to estimate the reference active power current component in dq-frame.

$$I_{d-ref} = \frac{P_{ref}}{V_{pcc-d}} \tag{4}$$

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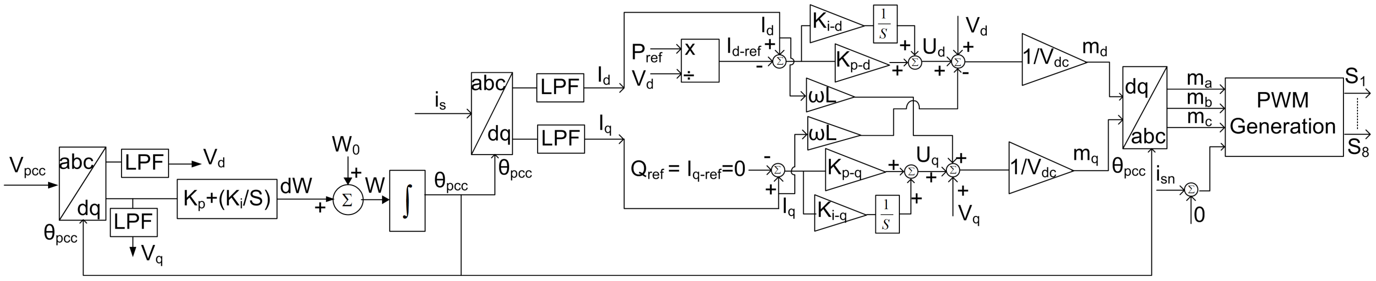

Fig. 3. Modified power Control technique for DG_1, DG_2 and DG_3.

Using park's transformation, equation (3) is transformed into synchronous dq-reference frame as,

$$V_{t-dq}e^{j\omega t} = RI_{dq}e^{j\omega t} + L\frac{dI_{dq}e^{j\omega t}}{dt} + V_{pcc-dq}e^{j\omega t} \tag{5}$$

By solving equation (5),

$$V_{t-dq} = j\omega LI_{dq} + RI_{dq} + L\frac{dI_{dq}}{dt} + V_{pcc-dq} \tag{6}$$

Where I_{dq} is state variable, V_{t-dq} is terminal voltage control input and V_{pcc-dq} is the disturbance input. In order to get desired control variable U_{dq}, error signal of dq-frame reference and actual current is passed through proportional and integral (PI) controller [29].

$$U_{dq} = RI_{dq} + L\frac{dI_{dq}}{dt} \tag{7}$$

Using equation (6) and (7),

$$V_{t-dq} = j\omega LI_{dq} + U_{dq} + V_{pcc-dq} \tag{8}$$

The VSC terminal voltage in dq-frame in terms of modulation index is,

$$V_{t-dq} = m_{dq}\frac{V_{dc}}{2} \tag{9}$$

Using equation (8) and (9),

$$m_{dq}\frac{V_{dc}}{2} = j\omega LI_{dq} + U_{dq} + V_{pcc-dq} \tag{10}$$

Decomposing equation (10) into real and imaginary parts,

$$m_d = \frac{2}{V_{dc}}(-\omega LI_q + U_d + V_{pcc-d}) \tag{11}$$

$$m_q = \frac{2}{V_{dc}}(\omega LI_d + U_q + V_{pcc-q}) \tag{12}$$

The modulating signals to drive the VSC in abc-frame are estimated by transforming equation (11) and (12). The block diagram representation of modified power control is shown in Fig. 3. The controller is designed in synchronous reference frame (dq-frame), for this the instantaneous phase is required. The PCC voltage is taken as feedback signal to extract the instantaneous phase of the micro-grid at respective PCC point. Currents supplied by the micro-grid to each residence ($i_{sa},\ i_{sb}\ and\ i_{sc}$) is taken as feedback signal for controller to generate control variables $m_a, m_b\ and\ m_c$. In order to generate the control variable m_n, reference neutral current is assumed zero and it is subtracted from the actual sensed neutral current.

B. Modified Control technique of DG_4

The modified control technique for DG_4 is designed in order to achieve power control mode during the grid connected mode of operation, seamless transition from grid connected mode to islanded mode, voltage control mode during islanded mode of operation and seamless re-synchronisation to the main grid from islanded mode of operation. When the micro-grid is operating in grid connected mode, the DG_4 operates in power control mode. During the fault in main grid, the micro-grid is islanded from main grid and controller of DG_4 is shifted to voltage control mode from power control mode. In this case, as micro-grid is isolated from main grid the instantaneous phase of the reference voltage is generated independently at 50 Hz frequency.

1) Mathematical modelling of voltage controller: In order to maintain reference voltage at the PCC4, the DG_4 is designed to control in dual loop control by considering voltage across the filter capacitor and the current through the inductor [30]. Hence the reference current is

$$\vec{i}_{ref} = C\frac{d\vec{v}_{pcc4}}{dt} \tag{13}$$

The equation (13) in dq-frame is,

$$i_{ref-dq}e^{j\omega t} = C\frac{d(V_{pcc4-dq}\ e^{j\omega t})}{dt} \tag{14}$$

$$i_{ref-dq} = C\frac{dV_{pcc4-dq}}{dt} + j\omega CV_{pcc4-dq} \tag{15}$$

Where $V_{pcc4-dq}$ is state variable. In order to get desired control variable i_{dq-c}, error signal of reference voltage (V_{dq-ref}) in dq-frame and actual voltage is passed through PI controller.

$$i_{dq-c} = C\frac{dV_{pcc4-dq}}{dt} \tag{16}$$

$$i_{ref-dq} = i_{dq-c} + j\omega CV_{pcc4-dq} \tag{17}$$

Decomposing equation (17) into real and imaginary

$$i_{ref-d} = i_{d-c} - j\omega CV_{pcc4-q} \tag{18}$$

$$i_{ref-q} = i_{q-c} + j\omega CV_{pcc4-d} \tag{19}$$

The estimated reference in dq-frame is then used to obtain modulating signals required to drive DG_4 VSC. These modulating signals are estimated by using mathematical model of power control from (2) to (12). So, the final modulating signals in dq-frame are

$$m_d = \frac{2}{V_{dc}}(-\omega LI_{q4} + U_{d4} + V_{pcc4-d}) \tag{20}$$

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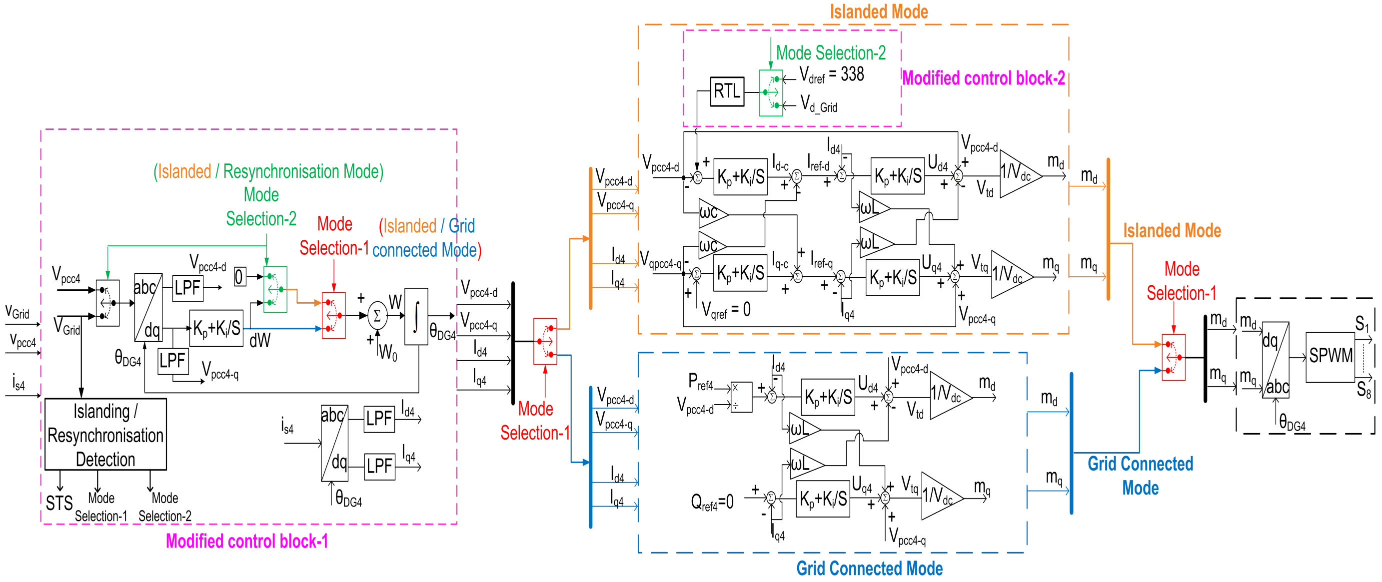


Fig. 4. Modified control technique for DG_4 in micro-grid to achieve seamless transition between Grid connected and islanded mode .

$$m_q = \frac{2}{V_{dc}}(\omega L I_{d4} + U_{q4} + V_{pcc4-q}) \qquad (21)$$

The modulating signals to drive the VSC in abc-frame are estimated by transforming equation (20) and (21).

Fig. 4 represents the block diagram of DG_4 controller. In grid connected mode of operation, the DG_4 is controlled as a power controlled source. Here, the synchronisation is done with the grid by using phase lock loop. Whenever fault occurred in the main grid, then the micro-grid is disconnected from the main grid by opening the static transfer switch and operate in islanded mode. While transferring micro-grid to islanded mode, the DG_4 controller is switched from power control mode to voltage control mode. In islanded mode, the micro-grid voltage is maintained by DG_4. During this sudden mode transition, it is very important to accurately select instantaneous phase angle problem of instantaneous phase jump in the micro-grid voltage. Here, to avoid this, the instantaneous phase angle value for the reference voltage is obtained from the previous estimated value during grid connected mode. This is achieved by switching the mode selection-1 in modified control block-1 as shown in Fig. 4. In islanded mode, the instantaneous phase for the reference voltage is generated at 50 Hz frequency independently.

Whenever fault is cleared in the main grid, then the micro-grid is switched to grid connected mode. Before switching to grid connected mode, the micro-grid voltage is re-synchronised with the main grid voltage. For this, the grid voltage is taken as reference to the voltage controller by switching the mode selection-2 as shown in Fig. 4. Sudden change in reference voltage reflects as spike in the micro-grid voltage. So to avoid this, the reference voltage is always passed through rate limiter (RTL) as shown in modified block-2 of Fig. 4. From this, the voltage spike is reduced while changing the reference voltage. Once the micro-grid voltage is synchronised with the main grid voltage, then micro-grid is reconnected to main grid by closing the static transfer switch.

TABLE I
THE MICRO-GRID SYSTEM PARAMETERS

Sr.No.	Parameter	Value
1	System Voltage	415V (L-L)
2	DG_1 Rating	20 kVA
3	DG_2 Rating	25 kVA
4	DG_3 Rating	15 kVA
5	DG_4 Rating	40 kVA
6	Line Impedance	1.334 Ohm, 3 mH
7	LC Filter $(L_f, R_f and\ C)$	6 mH, 0.15 Ω and 50 μ F
8	DC bus Voltage of each DG	760 V
9	Switching Frequency of each DG	3150 Hz

While transferring the micro-grid to grid connected mode, the DG_4 controller is switched to power control mode by switching the mode selection-1 as shown in Fig. 4.

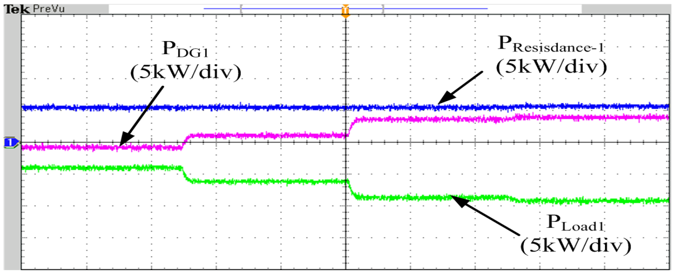
IV. PERFORMANCE EVALUATION OF PROPOSED MICRO-GRID USING REAL TIME SIMULATOR

The proposed micro-grid considered for the residential community is implemented in OPAL-RT real time simulator. The micro-grid parameters considered for real time implementation are given in Table I. The performance of proposed control scheme of DG's in micro-grid is evaluated in the following modes of operation

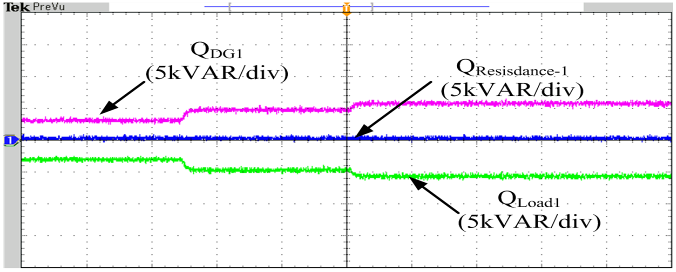
- Micro-grid in grid connected mode.
- Transition of micro-grid from grid connected mode to islanded mode.
- Micro-grid in islanded mode.
- Transition of micro-grid from islanded mode to grid connected mode.

A. Micro-grid in grid connected mode

When the micro-grid is operating in grid connected mode, then the micro-grid voltage is maintained by the main grid. The DG's in the micro-grid are controlled as power controlled

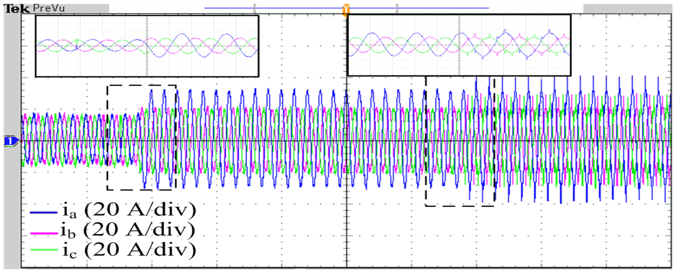


(a) Active power curves.

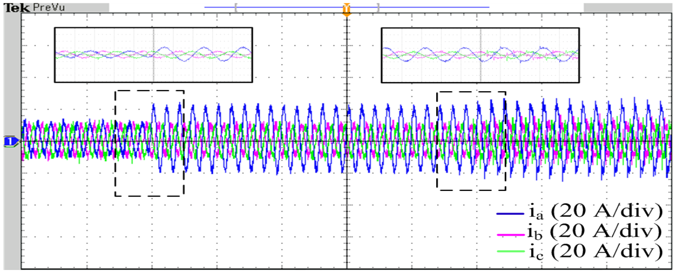


(b) Reactive power curves.

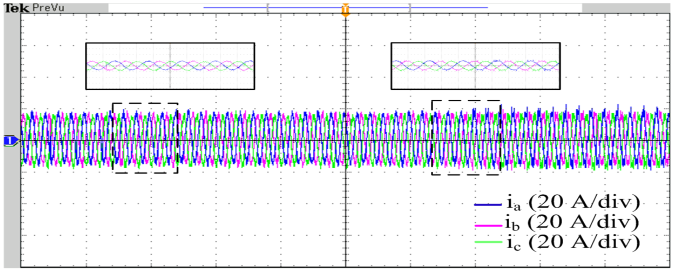
Fig. 5. Power curves in residence-1.



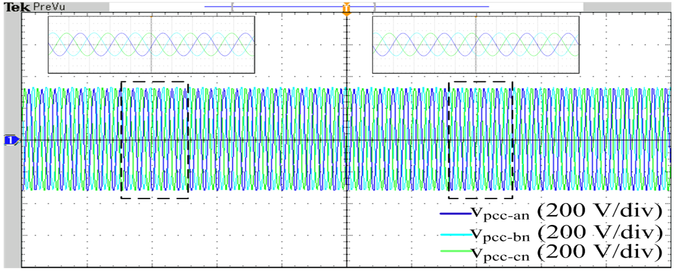
(a) Load current.



(b) DG_1 current.



(c) Residence-1 current (i_{s1}) from micro-grid.



(d) PCC-1 Voltage (v_{pcc-1}).

Fig. 6. Current waveforms in residence-1 and voltage at PCC-1.

sources. The performance of proposed modified power control technique of DG's in micro-grid is evaluated under the load disturbances and variation in solar power availability of DG_4.

The DG_1, DG_2 and DG_3 in residence-1, residence-2 and residence-3 are operate in charging mode and sharing mode. The major objectives of local DG's modified power control technique in residence-1, residence-2 and residence-3 are

1) To operate the residence at unity power factor in micro-grid,
2) To provide the transient free operation of micro-grid during each residential load disturbances (i.e the local load disturbances of residence-1, residence-2 and residence-3 should not reflect in micro-grid),
3) To absorb constant power from the micro-grid under residential load variations and maintain the power quality in the micro-grid by compensating the harmonics, unbalance load and reactive power demanded by the local loads in the residences.

With the knowledge of local load demand in the residences, the average load of the residence-1, residence-2 and residence-3 are predefined as 5kW, 8kW and 4kW. For simplicity the battery storage system capacity of each DG is selected as 150% of average local load demand. The local DG's in residence-1, residence-2 and residence-3 are controlled to absorb constant reference active power from the micro-grid. The reference power for DG_1, DG_2 and DG_3 in residence-1, residence-2 and residence-3 are 5kW, 8kW and 4kW respectively.

The local load demand in residence-1 is 4kW active power and 3kVAR reactive power. But the reference power for residence-1 is 5kW active power, so the remaining 1kW is stored in battery by DG_1 which is shown in Fig. 5(a). In order to operate the residence-1 at unity power factor in the micro-grid, the total reactive power demand by the local loads in residence-1 is supplied by DG_1 as shown in Fig. 5(b). If the local load demand in residence-1 is increased to 6kW active power and 4.5kVAR reactive power. Even though local load demand changed but the power demanded by residence-1 from micro-grid remains constant as 5kW. The additional 1kW active power is shared by DG_1 as shown in Fig. 5(a). In Fig. 5 it is observed that the micro-grid is transient free from local disturbances occurred in residence-1. Further the load demand in residence-1 is increased to 7kW active power which is unbalance, 5KVAR reactive power and non-linear load (bridge rectifier with resistive load of 450 Ω) is connected. The residence-1 absorbs constant 5kW active power at nearly unity power factor with balanced current, even though the local load is unbalance and nonlinear. The unbalance current, reactive power demand and harmonics are compensated by DG_1 as shown in Fig. 6. The power absorbed by the residence-1 from micro-grid remains constant as 5kW. Even though the local residential load changes as shown in Fig. 6(a), it is observed that the PCC voltage remains constant as shown

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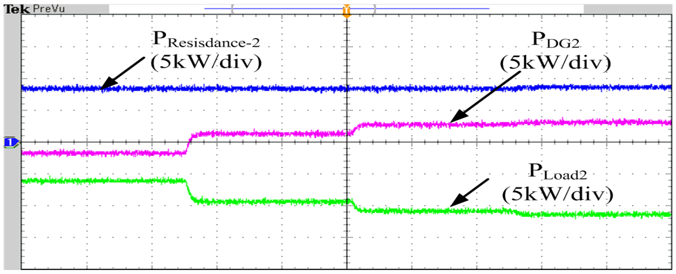
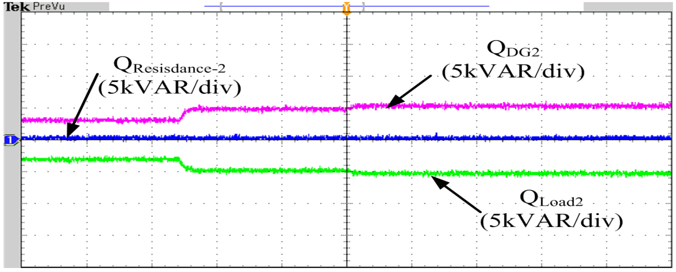
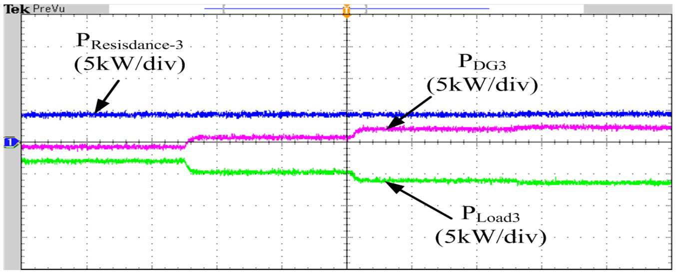


(a) Active power curves.

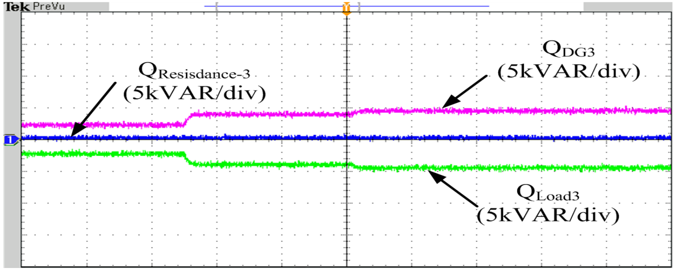


(b) Reactive power curves.

Fig. 7. Power curves in residence-2.



(a) Active power curves.



(b) Reactive power curves.

Fig. 8. Power curves in residence-3.

in Fig. 6(d). During dynamic load variations, in order to meet the local load variations, the control algorithm will change the modulating signal of the VSC of the respective DG, hence the PCC voltage is regulated.

Similarly, the dynamic performance of DG_2 and DG_3 controller in residence-2 and residence-3 are shown in Fig. 7 and Fig. 8. From figures it is observed that, both residences absorb constant active power from the main grid. However, sudden local load variations, reactive power demand, unbalanced current and harmonic current demand is compensated by respective residential DG.

The power input for DG_4 is solar power along with BES. The rating of battery storage system of DG_4 is selected as 150% of total average demand of micro-grid. The total demand in the micro-grid is 17kW (i.e sum of the power demand from the residence-1, residence-2 and residence-3). The DG_4 operate in three mode,

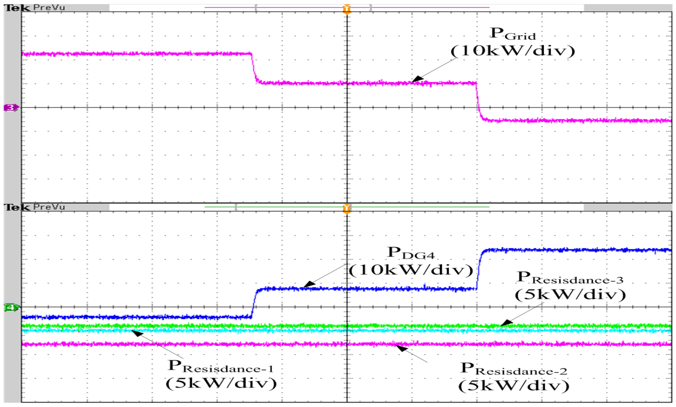


Fig. 9. Micro-grid power curves.

1) Charging mode.
2) Sharing mode.
3) Feeding mode.

1) Charging mode: when the solar power is not available and battery storage system of DG_4 is not fully charged, then the constant active power absorbed by the DG_4 from main grid is completely utilized to charge the BES of DG_4. In addition the active power demands of residence-1, residence-2 and residence-3 is also supplied by the main grid as shown in Fig. 9.

2) Sharing mode: When the solar power available with DG_4 is less than the total power demand from residence-1, residence-2 and residence-3, then the active power demanded by all residences is shared between main grid and DG_4. In Fig. 9, it is observed that solar power available with DG_4 of 7kW is supplied to all residences. However, the addition power demand of 10kW is supplied by main grid.

3) Feeding mode: When the BES of DG_4 is fully charged and the solar power available with DG_4 is greater than the total active power demand by all residences, then the surplus power is injected into main grid. In Fig. 9, it is observed that out of 23kW solar power available with DG_4, 17kW active power is supply to all residences. However, additional active power of 6kW is injecting into main grid.

B. Transition of micro-grid from grid connected mode to islanded mode

Under healthy grid condition the micro-grid is operating in grid connected mode. In this mode, proposed system power balance and the terminal voltage of the micro-grid is maintained by main grid. If any fault occurred in the main grid, then the micro-grid is disconnected from the main grid and operate in islanded mode. In this paper an intentional islanding is done, in order to observe the transition of micro-grid from grid connected mode to islanded mode. During this transition, the controller of DG_4 is switched to voltage control mode from power control mode. The micro-grid voltage in islanded mode is maintained by DG_4. For this, the instantaneous phase angle value for the reference voltage is obtained from the

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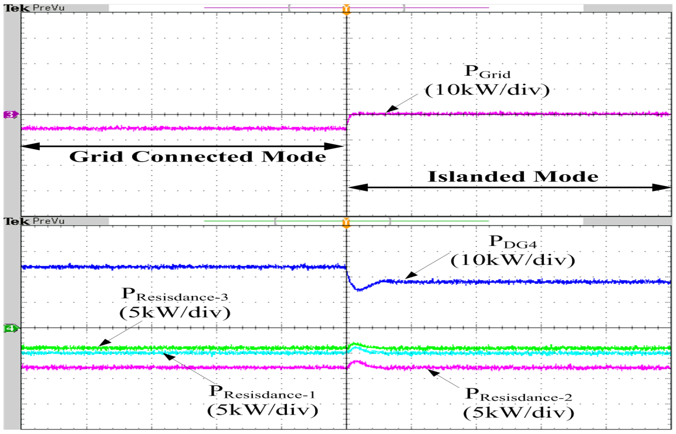

Fig. 10. Transition from grid connected to islanded mode.

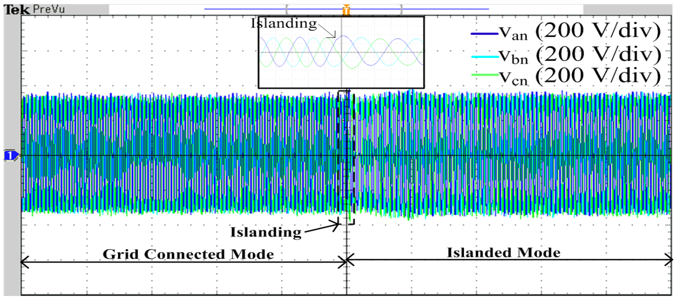

Fig. 11. PCC_4 voltage during grid connected to islanded mode.

previous estimated value during grid connected mode. This is achieved by switching the mode selection-1 in modified control block-1 as shown in Fig. 4. From this the instantaneous phase jump is avoided and smooth transition is occurred from the grid connected mode to islanded mode as shown in Fig. 11.

C. Micro-grid in islanded mode

During islanded mode of operation of micro-grid, the micro-grid voltage is maintained by the DG_4. In islanded mode DG_4 is controlled as voltage source. In this mode of operation, the controller of DG_1, DG_2 and DG_3 remains same as in grid connected mode. The residence-1, residence-2 and residence-3 demands constant load of 5kW, 8kW and 4kW which is completely supplied by the DG_4. However the local load disturbances are handled by the local DG's, these disturbances will not reflect in micro-grid as shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8. The harmonics and reactive power demand of local loads are compensated by the local DG's. Hence, proposed control scheme reduces the burden on DG_4 due to load disturbances, harmonics and reactive power demand of all the residential loads.

D. Transition of micro-grid from islanded mode to grid connected mode

When the main grid is in healthy condition (i.e grid fault is cleared), then the micro-grid is reconnected to the main grid. Before the reconnection of micro-grid with main grid, the

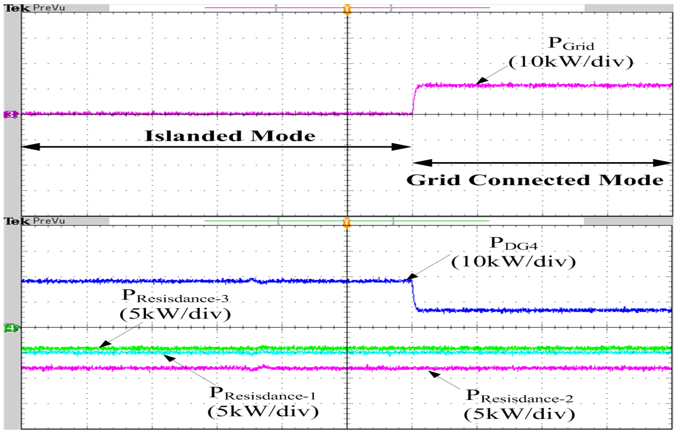

Fig. 12. Transition from islanded to grid connected mode.

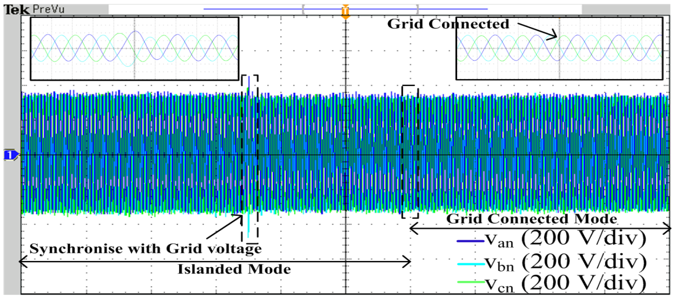

Fig. 13. PCC_4 voltage during islanded to grid connected mode.

micro- grid voltage is synchronised with the voltage magnitude and instantaneous phase of main grid by switching the mode selection-2 as shown in modified control block-1 of Fig. 4. The reference voltage for DG_4 is passed through rate limiter (RTL) as shown in modified control block-2 of Fig. 4, from this the spike in the micro-grid voltage is reduced while changing the voltage reference value. After the re-synchronisation of micro-grid voltage with main grid, the micro-grid is reconnected to the main grid by closing static transfer switch. From this, the smooth transition is occurred from the islanded mode to grid connected mode which can be observed in Fig. 13. During this mode, the controller of DG_4 is switched to power control mode from voltage control. However, the controllers of remaining DG's in residence-1, residence-2 and residence-3 are unchanged.

V. CONCLUSION

The performance of proposed micro-grid for the residential community under load disturbances, during grid connected mode, islanded mode and re-synchronisation of micro-grid to main grid is verified. The performance of modified power control technique is evaluated in order to achieve constant active power loading on the micro-grid by supplying additional active power residential load demand from respective residential DG. The residential sudden load variations, reactive power demand, unbalance current and harmonic current is compensated by respective residential DG. Hence, transient free operation of micro-grid is achieved. In addition, the smooth transition from grid connected mode to islanded mode and re-synchronisation to main grid is verified.

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