**International Journal of Power Electronics and Drive Systems (IJPEDS)**
Vol. 14, No. 1, March 2023, pp. 311~319
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i1.pp311-319

# Inter-connected AC/DC HMGS power management with 3-phase and 1-phase ILC

**Syed Abdul Razzaq, Vairavasamy Jayasankar**
Department of Electrical and Electronics Engineering, School of Electrical and Communication,
Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India

**Article Info**

***Article history:***

Received May 19, 2022
Revised Sep 20, 2022
Accepted Nov 3, 2022

***Keywords:***

BESS
Droop control
HMGS
ILC
Inter-connected

## ABSTRACT

In AC/DC hybrid micro grid system (HMGS) power converters are always tested for is performance in distribution, its ability to provide accurate power sharing, transient stability and load dynamics. The existing control methods either complex or limited to achieve optimal power flow. This paper proposes a modified decentralized droop control scheme for interlinking converter (ILC) connected to interconnected AC and DC grids. A three coordinated model is proposed where AC frequency, ILC power and DC voltage are corresponding axis. The power sharing through the ILC is dependent on the AC frequency droop and DC voltage droop which occurs due to overloading. The control scheme is designed for single and three phases ILC. The obtained results are compared with double loop control method which shows less frequency deviations, accurate power sharing. The ILC performs autonomously and transfer power bidirectional under islanded mode. The simulation is carried in MATLAB/Simulink.

*This is an open access article under the CC BY-SA license.*

***Corresponding Author:***

Syed Abdul Razzaq
Department of Electrical and Electronics Engineering, School of Electrical and Communication
Vel-Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology
No. 42, Avadi-Vel Tech Road Vel Nagar, Avadi, Chennai, Tamil Nadu 600062, India
Email: vtd516@veltech.edu .in

## 1. INTRODUCTION

The detailed micro grid (MG) architecture with converter control viz centralized and decentralized control scheme is discussed [1]. Decentralized control scheme for MG performs without communication link, as several control schemes like through droop control or reverse droop control, line impedance droop control, angle droop control, virtual impedance, adaptive voltage droop control [2]. A conventional method to control and operate single phase inverters connected in parallel to MG with reducing the harmonic distortion [3]. Interlinking converter (ILC) performance is always discussed for stability, excessive power losses the issues are highlighted and analyzed by controlling the voltage and current [4]. Centralized control with particle swarm optimization (PSO) method with maser and slave concept is proposed for controlling MG with renewable energy sources (RES) [5]. Electric vehicle is the present trend attracting researchers for integrating to MG, nano grid (NG) for two-way power flow through energy storage system (ESS), the power quality problems associate to grid are discussed with optimal solution by connecting filter and restorer [6]. A review paper discusses the power quality issues in bidirectional power flow in electric vehicle to grid [7]. To reduce the total harmonic distortion (THD) in a single-phase inverter a control technique confined band variable switching frequency pulse width modulation (CB-VSFPWM) is designed [8]. To extract maximum output power for a cluster MG, a modified reverse current flow method is proposed for radial system [9]. A multi-port DC-DC boost converter is designed for integrating PV and proton exchange membrane fuel cell

(PEMFC) [10]. A fuzzy logic controller is designed to drive and control the PV wind and battery system for smooth power output without fluctuation and maintains stable voltage and frequency [11].

The MG architecture, distribution, layouts with information technology-based control for series and parallel MG is elaborated [12]. There is always a risk in control of MG with communication-based control, as MG are at high chance of getting attacked by cyber security, a cyber cooperative control is designed for ILC for detecting the false signal attacks [13]. The fluctuation caused by the PV generation and battery will have adverse effect on power grid, structuring both PV and battery on a common DC bus by proposing hysteresis energy management for the DC bus and eliminate the frequent charging and discharging of battery system [14]. A voltage source converter (VSC) with microcontroller-based control is design for bidirectional power exchange [15]. A thorough study on ILC with its features and unresolved tasks when connected to islanded mode is elaborated [16]. Voltage drop and harmonic distortion are serious problems for power quality in MG, plenty of research has been done to compensate one such paper to is designed using adaptive neuro fuzzy inference system [17]. An optimal power routing scheme is designed for the ILC to reduce the unbalancing of power, losses of active power and the voltage deviations, an AC/DC converter of three phase with four leg is used for optimal power utilization where a IEEE13 bus system is used as unbalanced hybrid micro grid system hybrid micro grid system (HMGS) and IEEE-34 bus as unbalanced distribution network [18]. A five-level inverter is designed to ESS with a bidirectional power flow connected to AC/DC MG [19].

The modified decentralized control scheme is designed to power sharing and to avoid circulating currents through the converter [20]. A digital pulse width modulation (PWM) control is implemented for PV connected inverter with by synchronizing the output voltages and current [21]. This paper proposes a modified decentralized droop control scheme for ILC-1 for bidirectional power flow through AC/DC and interconnected single phase MG as shown in Figure 1.

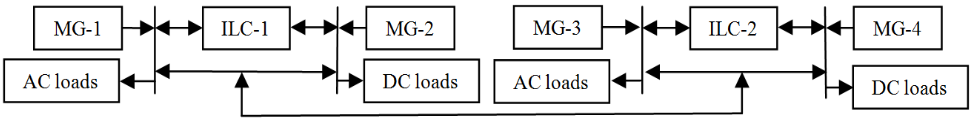

Figure 1. Block diagram of interconnected MGs

## 2. CONTROL AND OPERATION OF INTERCONNECTED MG

### 2.1. Droop control

In the era of modern power electronics inverters with extensive distribution can set their instantaneous active and reactive power with an extra communication cable. The droops are much similar which occurs in utility grids. The communication-based control makes a master slave operation which makes a complex control and moreover failure occurs due to one faulty point. In a decentralized droop control distributed generation (DG) has different owners, more flexible with a plug and play option, simple algorithm and faulty points can be healed without halting the system. Droop control for AC MG regulates the active power (P) versus frequency (F) and reactive power versus voltage (V) as described in (1), (2).

$$F_n = F_m + \alpha_m P_m \tag{1}$$

$$V_n = V_m + \beta_m Q_m \tag{2}$$

$$P_{load,ac} = \sum_{i=0}^{n} P_{ac}(i) * k_{ac}(i) \tag{3}$$

Where, $F_m$ and $V_m$ is frequency and voltage at peak, $\alpha_m$ and $\beta_m$ are the negative droop coefficients. Droop coefficients selection is relied on its rating (3) where $P_{ac}(i)$ is the power supplied from AC power station, unit $k_{ac}$ is the droop gain and number of units is given by $n$. DC droop control comparatively an easy task compared to AC droop control. The (4) defines the DC droop control by regulating DC power and DC voltage.

$$V_{dc,n} = V_{dc,m} + \gamma_m P_{dc,m} \tag{4}$$

$$P_{load,dc} = \sum_{i=0}^{n} P_{dc}(i) * \gamma_{ac}(i) \tag{5}$$

Where $V_{dc}$ is nominal DC voltage, $\gamma$ is the droop coefficient of unit m, $P_{dc}(i)$ is power supplied from DC power station and $\gamma$ is droop gain of DC power.

### 2.2. Detailed architecture of interconnected HMGS

The proposed design of interconnected HMGS shown in Figure 2 is referred from [22]. Four MG with DG and ESS are interconnected with two ILCs and loads. ILC performs autonomously which depends on the frequency and voltage values. A similar analysis on grid with RES and without RES is done for voltage stability, cost analysis for IEEE 14 bus and IEEE 30 bus [23]. Meanwhile another paper on multi-port ILC is discussed which is connected to HMGS to share power among grids with different voltage level [24]. ILC-1 used is a VSC with 6-IGBT/diode to perform bidirectional power flow and ILC-2 is VSC with 4-IGBT/diode. In case of ILC-1 the power is exchanged from AC grid to DC grid during the DC voltage droop which leads to increasing the frequency and to generate additional AC power to share from AC to DC via ILC-1, hence the converter behaves as rectifier and with positive sign of power. On frequency droop the power is transferred from DC grid to AC load, the power sign is negative and ILC-1 is termed as inverter.

The signs notations are reverse in case of ILC-2 for better results understanding that is during rectifier mode it signs negative and during inverter mode it signs positive. Autonomous bidirectional power transfer among AC and DC grids via ILCs is achieved through outer loop control. Frequency droop indicates power demand at AC load and voltage droop at DC indicates power demand at DC load. DC-capacitor connected to DC main voltage bus, LCL and LC filter connected to AC sub grid to eliminate the voltage ripples and current harmonics. Table 1 shows the HMGS parameter.

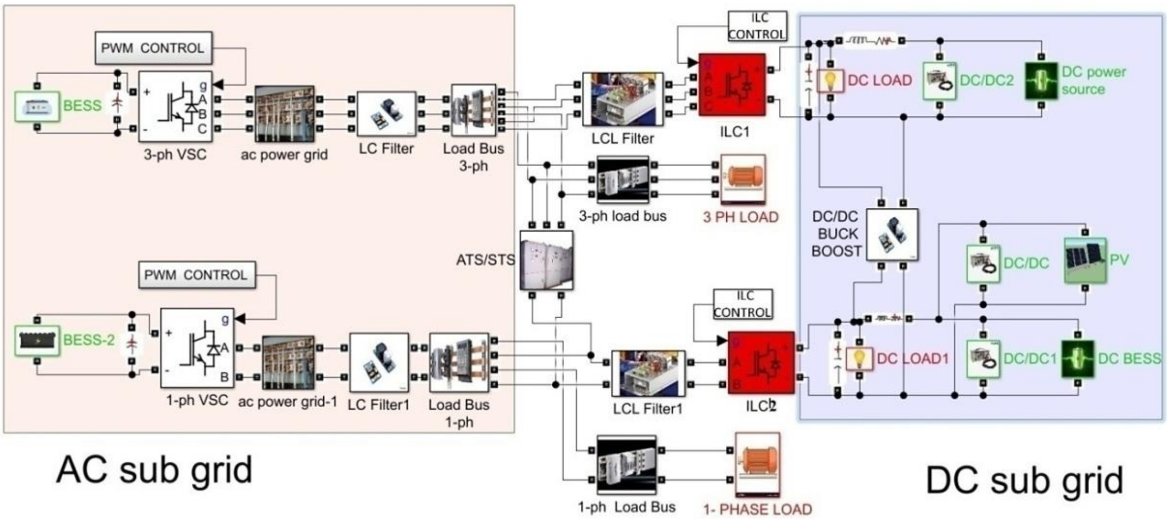

Figure 2. Simulation model of interconnected HMGS in MATLAB/Simulink

Table 1. Parameter of interconnected AC/DC HMGS

| AC-Sub Grid | ILC-1 | ILC-2 | DC-Sub Grid |
|---|---|---|---|
| MG voltage (3-ɸ,1-ɸ) V = 380 V, 220 V | ILC ref.$P_{con\_ref}$ = 10 | PI-1, $K_P$ =0.01, $K_I$ =25 | Voltage, $V_{dc}$ = 800 V, 370 V |
| System frequency, F = 60 Hz | KW | PI-2, $K_P$ =0.05, $K_I$ =25 | L= 5 mH, C=2200 µF |
| LC filter, L = 5 mH; C = 40 µF | PI controller-1, 2: - $K_P$ = 1, | PI-3, $K_P$ =0.08, $K_I$ =10 | Capacitance, C: DC-bus, |
| Line impedance, R = 0.01 Ω; | $K_I$ = 100, $K_P$ = 20, $K_I$ = 30 | | BESS, boost converter, LCL |
| L = 0.02 mH | Droop coefficients, α = | | filter: C=2000 µF,1000 µF, |
| LCL filter, L =2,4.2 mH; C = 60 µF | 0.00025; γ = 0.0005 | | 500 mF, 80 µF |
| Capacitor, C = 2200 µF | $V_{dc\_ref}$ = 800 V | | Inductance, L: DC bus, Boost |
| Inductance: LCL filter L=0.2 mH | Ref. frequency, $F_{ref}$ = 60 Hz | | converter, L=470 µH , 0.1 µH |

## 3. CONTROL OF ILCs

### 3.1. Control of ILC-1 for 3-phase

The proposed droop control method is shown in Figure 3. The mathematical relation for autonomous power exchange and balancing the power load demand on both sides of ILC-1 is expressed in (6), which describes the relation of DC-voltage, ILC power and frequency.

$$(\theta_1 1V - \theta_1 V_{ref}) + (\theta_2 P_{con} - \theta_2 P_{con_{ref}}) - (\theta_3 F - \theta_2 F_{ref}) = 0 \qquad (6)$$

The scaling values for $\theta_1$=0.3, $\theta_2$=0.007, $\theta_3$=10 is predefined to set the controller. In case of overload demand on AC load bus it will impact on the AC generation power grid given in (7).

$$\Delta P_{ac,load} = \Delta P_{gen,ac} - \Delta P_{con} \tag{7}$$

Droop in frequency happens due to change in AC load demand, which causes change in generating power at AC sub grid side which is verified by (8).

$$\Delta P_{gen,ac} = \frac{-P_{g,ac}}{\alpha}\Delta F \tag{8}$$

Sharing of active power $\Delta P_{con}$ from AC sub-grid to ILC and to DC load bus is expressed as (9).

$$\Delta P_{con} = -\frac{P_{con}}{\alpha}\Delta F + \frac{P_{con}}{\gamma}\Delta U \tag{9}$$

On solving (7) $\Delta P_{ac,\ load}$

$$\Delta P_{ac,load} = \frac{-P_{g,ac}}{\alpha}\Delta F - \left(-\frac{P_{con}}{\alpha}\Delta F + \frac{P_{con}}{\gamma}\Delta V\right) \tag{10}$$

The (10) explains the variations on frequency and DC voltage due to the change in AC load demand. When DC loads is overloaded, the power utilized by DC sub grid at the load side is the sum of total power supplied by DC power and power shared by ILC-1 from AC sub-grid expressed in (11).

$$\Delta P_{dc,load} = \Delta P_{gen,dc} + \Delta P_{con} \tag{11}$$

DC droop illustrate any changes in DC voltage has its consequence on generation of DC power (12).

$$\Delta P_{dc,gen} = -\frac{P_{g,dc}}{\gamma}\Delta V \tag{12}$$

Power sharing due to changes in DC load has a impact on frequency and DC voltage which given by (13).

$$\Delta P_{dc,load} = \left(\frac{-P_{con}}{\alpha}\right)\Delta F + \left(\frac{-P_{con}}{\gamma} + \frac{P_{con}}{\gamma}\right)\Delta V \tag{13}$$

A control method for charging and discharging of battery energy storage system (BESS) is considered from [25]. AC/DC MG is integrated with BESS is referred from [26]. A DC/DC bidirectional converter is designed for BESS with voltage and current controlled [27]. A PID controller is adopted for controlling a buck boost converter [28].

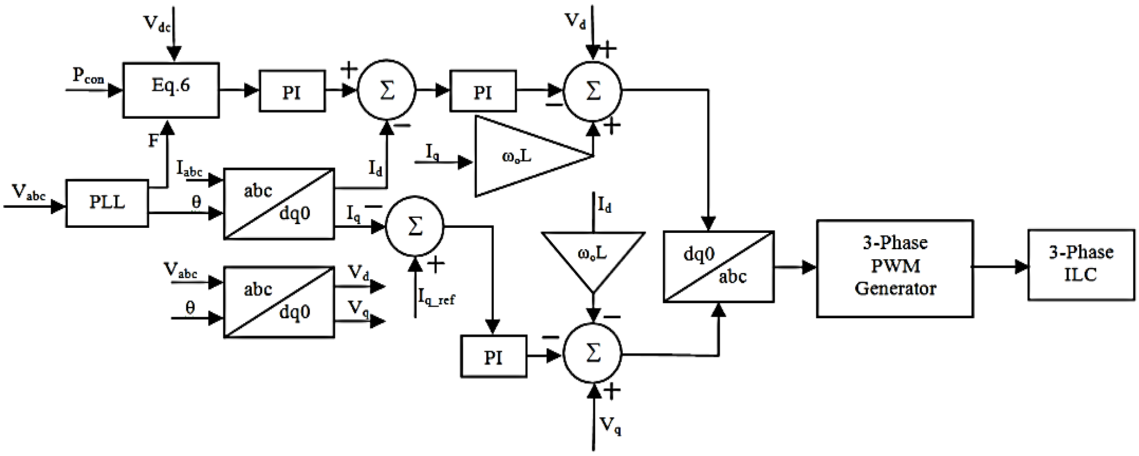

Figure 3. Control scheme for 3-phase ILC-1

### 3.2. Control of ILC-2 for 1-phase

The Figure 4 illustrates the control method of 1-phase ILC-2 which intends to perform the autonomous bidirectional power transfer. Using phase lock loop (PLL) to generate the current and voltage reference signals. The PV system generates 4 KW of power with output voltage of 200 V at DC main bus 370 V is maintained by the use of boost converter. BESS output voltage of 420 V is boost to 800 V which feeds the critical load bus. Control and monitoring of voltages and currents through BESS and PV are done by tuning PI controllers. The inner loop control maintains the current in the set range while the outer loop control compares with the reference values of voltage and restricts within limits. The optimal control of PI control depends on duty cycle. Performance of inner loop is more accurate and faster due to corner frequency greater compare to outer loop. PI controller is still an absolute selection for unstable system. This proposed method is a simple and robust for sharing power to either side of ILC on power demand.

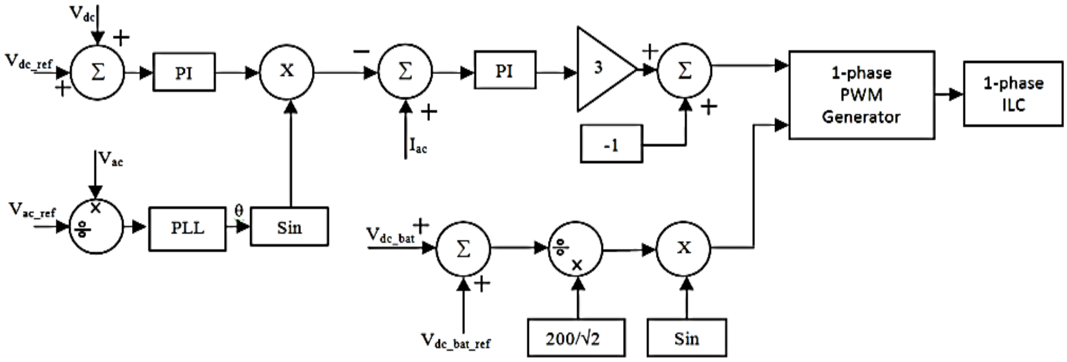

Figure 4. Control scheme of 1-phase ILC-2 (voltage control-outer loop, current control-inner loop)

## 4. RESULTS AND DISCUSSION

The paper explains the optimal power management for HMGS connected with multiport ILC with a distributed coordinated control with bidirectional power flow [29]. A conventional droop control method is designed for ILC power autonomous power sharing [30]. Due to load variation in AC and DC it impacts on frequency and DC voltage. To achieve the limitations of conventional droop control method and line impedance during nonlinear loads a novel method is discussed [31]. In this proposed paper AC generation is of 120 KW capacity and the load of 90 KW. The DC power generates up to 45 kW with the DC maximum load of 75 KW. AC MG voltage is 3-phase with 380 V, 1-phase 220 V and DC bus voltage is 800 V, 370 V. The acceptable voltage range is ±5% and for frequency is ±3%. Controller scaling factor $\theta_1$, $\theta_2$, $\theta_3$, are considered for autonomous functioning. The frequency drop of 0.00008 and DC voltage droop is 0.0006. A paper is presented on interlinking converter for hybrid AC/DC MG for optimal power flow with stable voltage [32]. Table 2 explains the complete performance of MG during various circumstances load variation.

Table 2. Power distribution to load from power source and power transfer from ILC-1,2

| Time(s) | | | ILC-1 | | | | | ILC-2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3-Phase Load (KW) | DC load (KW) 800V | ILC-1 (KW) Rect./Inv | AC Source (KW) | DC Source (KW) | 1-Phase Load (KW) | DC load (KW) 370V | ILC-2 (KW) Rect./ Inv. | AC Source (KW) | DC Source (KW) | 3-Phase Load (KW), |
| 0 | 40 | 15 | 10, Rect. | 50 | 5 | - | 20 | 16, Rect. | 16 | 4 | 40 |
| 0.5 | - | - | - | - | - | - | 18 | 18, Rect. | 18 | | - |
| 1 | 0 | 25 | 25, Rect. | 25 | 0 | - | 12 | 12, Rect. | 12 | | 0 |
| 1.5 | - | - | - | - | - | - | 5 | 5, Rect. | 5 | | - |
| 1.6 | 50 | 0 | 40, Inv. | 10 | 40 | - | | | | | 50 |
| 2 | - | - | - | - | - | 10 | - | 10, Inv | | 10 | - |
| 2.5 | - | - | - | - | - | 5 | - | 05, Inv | | 5 | - |
| 3 | - | - | - | - | - | 5 | - | 50, Inv | | 5 | - |
| Total | 90 | 40 | | 85 | 45 | 20 | 55 | | 51 | 24 | 90 |

### 4.1. ILC performs as rectifier

At time t=0-1 s AC source generates 50 KW, the AC load-1 consume 40 KW and access 10 KW is supposed to transferred to utility grid or DC grid. Meanwhile DC load-1 of 15 KW is turned on and DC power generates about 5 KW due to insufficient power demand decrease in voltage from 800 V to 790 V, converter-1transfer active power of 10 KW supplied by AC sub grid with frequency variation of 0.1 Hz. At t=1s a DC load-2 of 60 KW is connected which decrease voltage to 780 V, hence power is shared from AC sub-grid via ILC-1. Figure 5 shows the power transfer through ILC-1.

Similarly, for ILC-2 DC linear loads at time t=0s, 0.5s, 1s, 1.5s with capacity of 20 KW, 18 KW, 12 KW, 5 KW is connected. PV output of 4 KW on DC sub grid which is delivered to load-1 and for remaining loads, power is transferred from AC single-phase sub-grid via ILC-2. The power delivered through BESS, PV and ILC are shown in Figure 6. Figure 7 shows the variation in frequency during load changes for ILC-2.

$$\text{AC power} \xrightarrow{ILC(as\ Rectifier)} \text{DC Load} = \begin{cases} P_{ac,gen} > P_{ac,load} \text{ also } P_{ac,gen} > P_{dc,gen} \\ P_{dc,load} > P_{dc,gen} \text{hence } P_{con} \text{ shares power to DC load} \end{cases} \quad (13)$$

## 4.2. ILC performs as inverter

At t=1.6s 50 KW of load on AC side is connected. Since 120 KW capacity of AC grid is connected to loads and already 110 KW is supplied to loads, as the frequency drop of 0.1 Hz is sensed by controller. The requirement of 40 KW is supplied by DC sub grid by adding additional string to BESS to boost the power capacity. Power is transferred from upgraded BESS at DC side to AC load side via ILC-1. Hence ILC-1 performs as inverter with negative sign.

For ILC-2 during t=2s, 2.5s, 3s AC load of 10 KW, 5 KW, 5 KW is connected and previously connected DC loads and AC power is disconnected. DC side BESS is connected to DC main grid to deliver the power to AC loads, hence ILC-2 acts as inverter and sign is positive, results are shown in Figure 8.

$$\text{DC power} \xrightarrow{ILC(as\ Inverter)} \text{AC Load} = \begin{cases} P_{dc,gen} > P_{dc,load} \text{ also } P_{dc,gen} > P_{ac,gen} \\ P_{ac,load} > P_{ac,gen} \text{hence } P_{con} \text{ shares power to AC load} \end{cases}$$

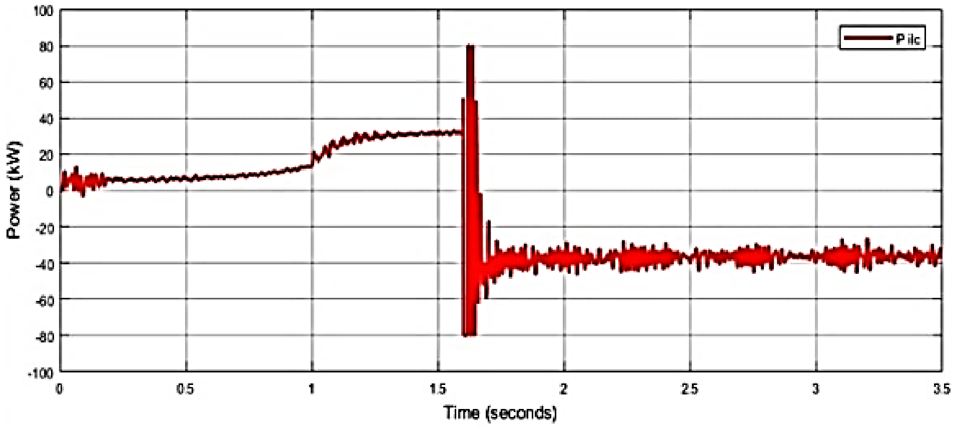

Figure 5. Power transfer through ILC-1

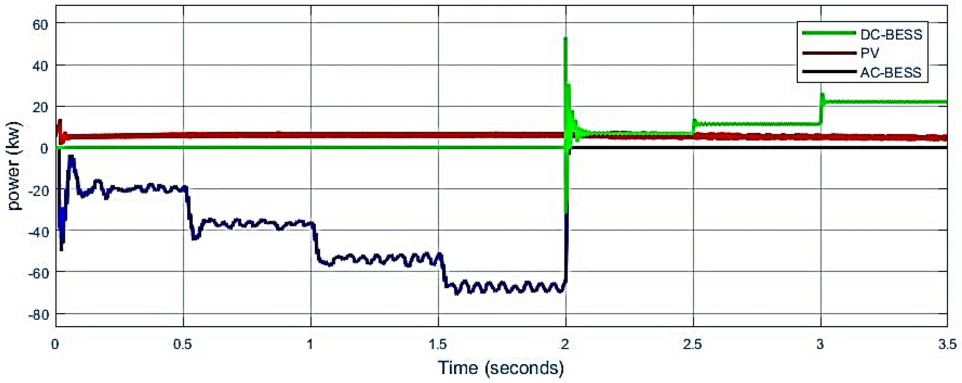

Figure 6. Power waveform of AC/DC BESS, PV

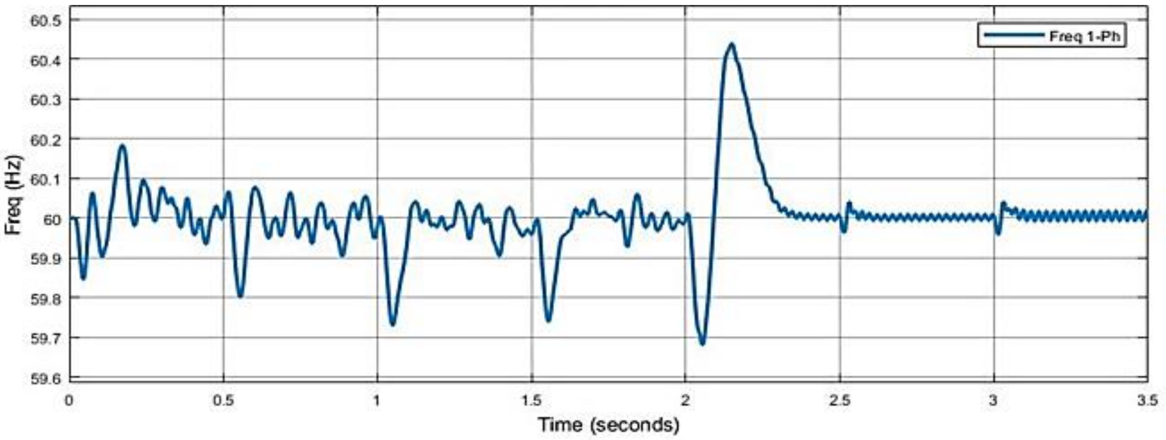

Figure 7. Frequency variations in ILC-2

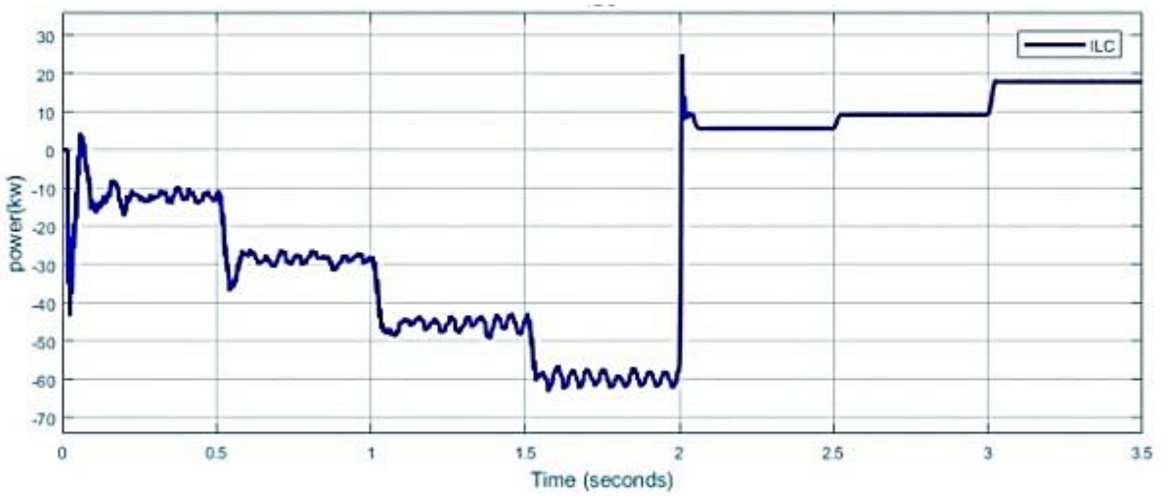

Figure 8. Power transfer through ILC-2

## 5. CONCLUSION

This paper proposes a modified decentralized droop control scheme for ILC in islanded mode of operation and when connected to inter-tied MG which delivers autonomous bidirectional power sharing for AC/DC HMGS. The ILC activates and shares power upon droop in AC frequency and DC voltage when loads are changed from under loaded to overloaded condition. The following points can be concluded from the proposed paper: Based on the droop coefficients the converter share power with a simple 3-coordinated mathematical model which is regulated with AC frequency, DC voltage and ILC power. Excess power can be transferred to either side of grid or utility grid or to BESS for charging purpose. This forms the optimum power utilization. Three phase converters can share the power to single phase grid via ATS/STS or via buck boost converter. Plug and play feature with future extension of adding active and passive sources. The simulation results are evident for a reliable, secure from system during blackouts, better performance in power distribution, accuracy of power sharing autonomously without communication link. Finally proposed AC/DC HMGS structure provides a clear idea of up gradation of NG to MG and controls the frequency deviations and voltage sag due to load variation.

## REFERENCES

[1] M. S. B. Arif and M. A. Hasan, “Microgrid architecture, control, and operation,” *Hybrid-Renewable Energy Systems in Microgrids*, pp. 23–37, 2018, doi: 10.1016/B978-0-08-102493-5.00002-9.

[2] P. Zafari, A. Zangeneh, M. Moradzadeh, A. Ghafouri, and M. A. Parazdeh, “Various droop control strategies in microgrids,” *Microgrid Architectures, Control and Protection Methods*, pp. 527-554, 2020, doi: 10.1007/978-3-030-23723-3_22.

[3] J. E. Mariachet, J. Matas, H. Martín, and A. Abusorrah, “Power calculation algorithm for single-phase droop-operated inverters considering nonlinear loads and unsing n-order SOGI filtering,” *International Conference on Renewable Energies and Power Quality*, 2018, vol. 1, no. 16, pp. 710-715, doi: 10.24084/repqj16.442.

[4] X. Shen, D. Tan, Z. Shuai and A. Luo, “Control techniques for bidirectional interlinking converters in hybrid microgrids: leveraging the advantages of both ac and dc,” *IEEE Power Electronics Magazine*, vol. 6, no. 3, pp. 39-47, 2019, doi: 10.1109/MPEL.2019.2925298.

[5] N. H. Saad, A. A. El-Sattar, and A. E.-A. M. Mansour, “A novel control strategy for grid connected hybrid renewable energy systems using improved particle swarm optimization,” *Ain Shams Engineering Journal*, vol. 9, no. 4, pp. 2195-2214, 2018, doi: 10.1016/j.asej.2017.03.009.

[6] S. S. Rao and D. Rangaswamy, “Power quality mitigation and transient analysis in AC/DC hybrid microgrid for electric vehicle charging,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 3, pp. 1315-1322, 2021, doi: 10.11591/ijeecs.v24.i3.pp1315-1322.

[7] B. N. Harish and U. Surendra, “A review on power quality issues in electric vehicle interfaced distribution system and mitigation techniques,” *Indonesian Journal Electrical Engineering and Computer Science*, vol. 25, no. 2, pp. 656-665, 2022, doi: 10.11591/ijeecs.v25.i2.pp656-665.

[8] H. Attia, H. S. Che, T. K. Suan Freddy, and A. Elkhateb, “Bipolar and unipolar schemes for confined band variable switching frequency PWM based inverter,” *International Journal Electrical and Computer Engineering*, vol. 11, no. 5, pp. 3763-3771, 2021, doi: 10.11591/ijece.v11i5.pp3763-3771.

[9] K. Sivakumar, R. Jayashree and K. Danasagaran, “A novel branch current flow-based construction of microgrids,” *Indonesiam Journal Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 28-36, 2021, doi: 10.11591/ijeecs.v21.i1.pp28-36.

[10] I. Alhamrouni, M. Salem, Y. Zahraoui, B. Ismail, A. Jusoh, and T. Sutikno, “Multi-input interleaved DC-DC converter for hybrid renewable energy applications,” *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 3, pp. 1765-1778, 2022, doi: 10.11591/eei.v11i3.3779.

[11] O. Feddaoui, R. Toufouti, L. Jamel, and S. Meziane, ‘Fuzzy logic control of hybrid systems including renewable energy in microgrids,” *International Journal Electrical & Computer Engineering*, vol. 10, no. 6, pp. 5559-5569, 2020, doi: 10.11591/ijece.v10i6.pp5559-5569.

[12] E. B. Massagué, F. D. González, M. A. Peñalba, F. G. Llistuella, P. O. Rosell, and A. Sumper, “Microgrid clustering architectures,” *Applied Energy*, vol. 212, pp. 340-361, 2018, doi: 10.1016/j.apenergy.2017.12.048.

[13] Y. Wang, S. Mondal, C. Deng, K. Satpathi, Y. Xu and S. Dasgupta, “Cyber-resilient cooperative control of bidirectional interlinking converters in networked AC/DC microgrids,” *IEEE Transactions on Industrial Electronics*, vol. 68, no. 10, pp. 9707-9718, 2021, doi: 10.1109/TIE.2020.3020033.

[14] H. Wu, S. Wang, B. Zhao, and C. Zhu, “Energy management and control strategy of a grid-connected PV/battery system: Energy Management And Control Strategy,” *International Transactions on Electrical Energy Systems*, vol. 25, no. 8, pp. 1590-1602, 2015, doi: 10.1002/etep.1926.

[15] M. Khobragade, H. S. Dalvi, and P. Jagtap, “Bidirectional voltage source converter for microgrid,” *Smart Technologies for Energy, Environment and Sustainable Developmen*t, *Eds. Singapore: Springer Singapore*, 2019, pp. 29-40. doi: 10.1007/978-981-13-6148-7_4.

[16] A. Ordono, E. Unamuno, J. A. Barrena, and J. Paniagua, “Interlinking converters and their contribution to primary regulation: a review,” *International Journal of Electrical Power & Energy Systems*, vol. 111, pp. 44-57, 2019, doi: 10.1016/j.ijepes.2019.03.057.

[17] S. Sumana, R. Dhanalakshmi and D. Dhomodharan, “Validation of photovoltaics powered UPQC using ANFIS controller in a standard microgrid test environment,” *International Journal Electrical and Computer Engineering*, vol. 12, no. 1, pp. 9-101, 2022, doi: 10.11591/ijece.v12i1.pp92-101.

[18] M. M. Esfahani, H. F. Habib, and O. A. Mohammed, “Optimal power routing scheme between and within interlinking converters in unbalanced hybrid AC–DC microgrids,” *IET Generation Transmission & Distribution*, vol. 14, no. 3, pp. 368-378, 2020, doi: 10.1049/iet-gtd.2019.0061.

[19] T. C. Ting, Z. Rasin, and C. S. Ching, “Design and simulation of cascaded H-bridge multilevel inverter with energy storage,” *Indonesian Journal Electrical Engineering Computer Science*, vol. 23, no. 3, pp. 1289-1298, 2021, doi: 10.11591/ijeecs.v23.i3.pp1289-1298.

[20] H. Saghafi and H. R. Karshenas, “Power sharing improvement in standalone microgrids with decentralized control strategy,” *Electric Power Components and Systems*, vol. 42, no. 12, pp. 1278-1288, 2014, doi: 10.1080/15325008.2014.927030.

[21] L. Hassaine and M. R. Bengourina, “Design and control technique for single phase bipolar H-bridge inverter connected to the grid,” *International Journal of Electrical and Computer Engineering*, vol. 10, no. 3, pp. 3057-3065, 2020, doi: 10.11591/ijece.v10i3.pp3057-3065.

[22] P. C. Loh, D. Li, Y. K. Chai and F. Blaabjerg, “Autonomous control of interlinking converter with energy storage in hybrid AC–DC microgrid,” *IEEE Transactions on Industry Applications*, vol. 49, no. 3, pp. 1374-1382, 2013, doi: 10.1109/TIA.2013.2252319.

[23] H. J. Queen, J. Jayakumar and T. J. Deepika, “Comparative techno-economic analysis of power system with and without renewable energy sources,” *Indonesian Journal Electrical Engineering and Computer Science*, vol. 24, no. 3, pp. 1260-1268, 2021, doi: 10.11591/ijeecs.v24.i3.pp1260-1268.

[24] J. Khodabakhsh and G. Moschopoulos, “Simplified hybrid AC–DC microgrid with a novel interlinking converter,” *IEEE Transactions on Industry Applications*, vol. 56, no. 5, pp. 5023-5034, 2020, doi: 10.1109/TIA.2020.2996537.

[25] G. I. Hasyim, S. Wijanarko, J. Furqani, A. Rizqiawan, and P. A. Dahono, “A current control method for bidirectional multiphase DC-DC boost-buck converter,” *International Journal Electrical Computer Engineering*, vol. 12, no. 3, pp. 2363-2377, 2022, doi: 10.11591/ijece.v12i3.pp2363-2377.

[26] S. Gaurav, C. Birla, A. Lamba, S. Umashankar, and S. Ganesan, “Energy management of PV – battery based microgrid system,” *Procedia Technology*, vol. 21, pp. 103-111, 2015, doi: 10.1016/j.protcy.2015.10.016.

[27] T. C. Ting, Z. Rasin, and C. S. Ching, “Design and simulation of cascaded H-bridge multilevel inverter with energy storage,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 3, pp. 1289-1298, 2021, doi: 10.11591/ijeecs.v23.i3.pp1289-1298.

[28] S. W. Shneen, D. H. Shaker, and F. N. Abdullah, “Simulation model of PID for DC-DC converter by using MATLAB,” *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 3791-3797, 2021, doi: 10.11591/ijece.v11i5.pp3791-3797.

[29] M. Abuhilaleh, L. Li, J. Zhu and M. J. Hossain, “Distributed control and power management strategy for parallel bidirectional power converters in hybrid microgrids,” *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, 2019, pp. 2148-2153, doi: 10.1109/IECON.2019.8927695.

[30] P. C. Loh, D. Li, Y. K. Chai, and F. Blaabjerg, “Autonomous operation of ac–dc microgrids with minimised interlinking energy flow,” *IET Power Electronics*, vol. 6, no. 8, pp. 1650-1657, 2013, doi: 10.1049/iet-pel.2012.0567.

[31] X. Hoa Thi Pham, “Power sharing strategy in islanded microgrids using improved droop control,” *Electric Power Systems Research*, vol. 180, p. 106164, 2020, doi: 10.1016/j.epsr.2019.106164.

[32] H. Afianti, O. Penangsang, and A. Soeprijanto, “Stability and reliability of low voltage hybrid AC-DC microgrids power flow model in islanding operation,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 1, pp. 32-41, 2020, doi: 10.11591/ijeecs.v19.i1.pp32-41.

## BIOGRAPHIES OF AUTHORS

**Syed Abdul Razzaq** is a Research Scholar in Electrical and Electronics Engineering Department at Vel-Tech Rangarajan Dr. Sagunthala R & D Institute of Science and Technology, Chennai, India. He received his B.Tech. M.Tech. Degrees in Electrical and Electronics Engineering and Power Electronics from University of Jawaharlal Nehru Technology. His research interests include the field of HMGS, Smart Grid & Micro Grid, Power Electronics, BESS, Battery Chargers, Inverters, Renewable Energy, Data Centers, Data Center Infrastructure Management, Industrial Automation and Sub-Station Automation. He can be contacted at email: vtd516@veltech.edu.in.

**Vairavasamy Jayasankar** Prof. in Electrical & Electronic Engineering Department and Dean-School of Electrical and Communication, Vel-Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India. He has completed his Ph.D from Anna University. He has vast experience in academics; he has published several papers in reputed journals, national and international conferences. His research of interest is in High Voltage Engineering, Power System Voltage Stability, Power Electronic Converters and Renewable Energy Sources. He can be contacted at email: deansoe@veltech.edu.in.