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Autonomous power sharing for AC/DC HMGS using decentralized modified droop method for interlinking converter

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

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ABSTRACT

The present trend of integrating renewable energy sources (RES) in AC/DC hybrid micro grid systems (HMGS) has certainly reduced the greenhouse gases and provides the variety of power sources for micro grid (MG). Interlinking converter (ILC) is the main converter for interconnecting AC/DC sub-grids with a variety of features like autonomous bidirectional power sharing, reducing the power conversions in the grid and additionally a featuring aspect for energy management system (EMS). Interlinking converters are desired to maintain stable frequency, constant voltages at buses, reduce the power losses, reduce switching losses and control on circulating currents, most of the control methods could not achieve all. In this paper, the decentralized modified droop control method is presented which is significant in meeting the autonomous bidirectional AC/DC power load demand and in achieving the desired features. A three coordinated model is proposed where AC frequency, ILC power and DC voltage are the corresponding axis. The power sharing through the ILC is dependent on the AC frequency droop and DC voltage droop which occurs due to overloading. This control scheme is compatible for interconnection with multi-port grids. This control schemes provide more reliable, stable and accurate results compare to conventional droop methods.

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Corresponding Author:

Syed Abdul Razzaq
Department of Electrical and Electronics Engineering
Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology
Chennai, India
Email: vtd516@veltech.edu.in

1. INTRODUCTION

The revolution of RES and its contribution to the large power system have certainly reduced the energy production costs. For economical and functional of hybrid micro grid systems (HMGS), power sources are made to integrate with distributed generation (DG) and energy storage system (ESS) more often which in-fact makes HMGS with less polluted provides clean energy, reliable and overall improved efficiency as shown in Figure 1. The challenges in-order to operate the HMGS is stability, power quality, voltage and frequency control in the sub-grids. Interlinking converter (ILC) have been proven to reduce the power conversion in HMGS and has the capability to circulate the required active power to either side of the AC/DC grids. The ILC performs autonomous power exchange based on the droop control scheme where the AC active power and frequency are regulated also AC voltage and reactive power are regulated of AC grid and for DC grid the active power and DC voltage are regulated.

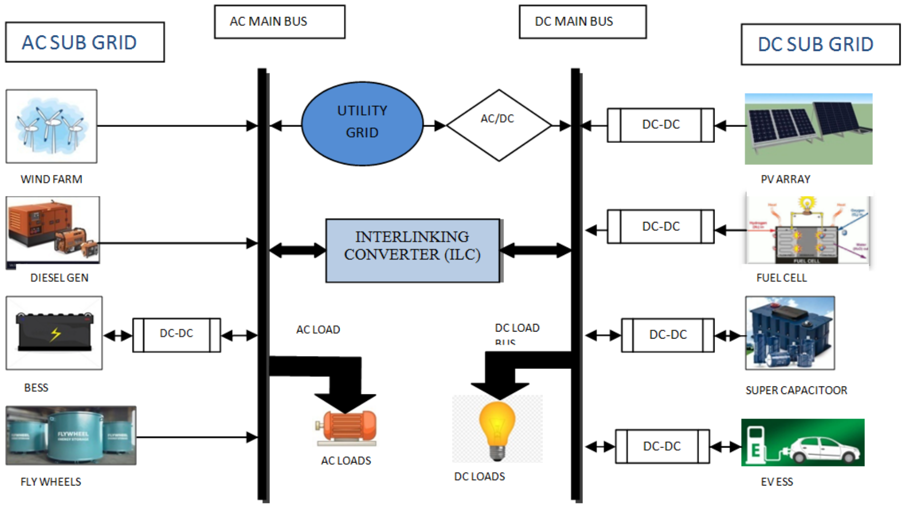

Figure 1. Structure of AC/DC HMGS

A survey paper on power management with different control strategies is discussed [1]. Clean energy is important aspects in HMGS and its roles are explained with advantages, restrictions and limitations [2]. DG source requires regular monitoring for valuable returns, as the power generated may not be utilized at that moment such power is stored in large capacity batteries, super capacitors, one such method of monitoring is done by fuzzy logic controller [3]. A four port converter is designed to control the secondary phase shifting for a PV and battery system for DC sub grid, the approach is achieved with simplified architecture, high power density and also eliminating the current ripples [4]. In contrast adaptive fractional fuzzy sliding mode control (AFFSMC) scheme is explained for power management (PM) with distinguish RES [5]. In MG BESS play a vital role due to the expansion of hybrid electric vehicle (HEV), battery management system (BMS) are in being rapid research for its performances, protection, capacity, and integration with AC and DC loads with converters connected [6]. A BMS scheme is developed using a fuzzy logic control for a PV connected system for charging and discharging and also to achieve maximum power which is connected to MG [7].

A review paper on smart grid with the scope of information and communication technologies are reviewed with the challenges at plant level, utility control center, transmission side, for reliability, data management and cyber security issues [8]. Internet of things (IoT) based centralized control is design for MG which help is load management for remote areas, this scheme depends on the single circuit breaker switch which make the system less reliable [9]. In an another paper author proposed a nonlinear control strategy for PV and wind connected system to MG which efficiently extracts the maximum power from the DG by applying the Lyapunov's stability theory at rotor and grid side converters [10]. Model predictive control technique is designed for the HMGS, model predictive current and power (MPCP) control scheme which controls BESS which in-fact helps to develop a reliable method for building the EMS, this method controls the AC/DC bus voltages [11]. To limit the double grid frequency for loads consuming active and reactive power during unbalanced conditions a control scheme is developed using proportional integral (PI) controller synchronous reference [12]. Additionally other control techniques like synchronous based generator, artificial intelligence, artificial neural network, improved particle swarm optimization for HMGS in islanded mode are described in [13], [14]. Other features of controlling ILC like the issues of impulse current during grid connection, other conventional interconnection and techniques are analyzed [15].

The different schemes of identification of direction and magnitude of converter operation for bidirectional power exchange which also improve the power quality of the system is explained [16]. Different schemes are described to achieve the bidirectional power transfer which mainly relies on the stability with GPS accuracy [17]. The HMGS with multi-port ILC has a special control scheme with unidirectional DC-DC sub-converter (UDDSC) which maintain DC voltages connected at DC grid system and supplying constant DC voltage and minimizing the complexity [18]. However need–based distributed coordination strategy for islanded HMGS using electric vehicle (EV) which opts decentralized mode of operation for requirement of power load is fulfilled [19]. Optimal power sharing (OPS) method to balance the droop characteristics of AC/DC grids, it's a zonal power sharing mode but the method is adopted under the centralized scheme only and hierarchical power sharing scheme which makes the complete sensors to perform live 24/7 to show the accurate results [20]. One of the major concern of HMGS are always the circulating current this paper overcomes the issue with efficiently designing the dq-0 axis [21].

This proposed decentralized droop method for voltage and frequency control for ILC, balances the real time load sharing demand under balanced conditions. ESS and DG are integrated to serve the power to the load. Unlike the constant voltage and constant frequency this method can be adopted to wide ranges. Anyhow while setting the voltage within the limit the active power can be restricted to limited limits [22]. Stability, frequency deviation under islanding mode can be easily controlled via decentralized mode via phase angle, inverse droop control by adding a virtual impedance [23]. Whereas another control method uses only PI controller for controlling voltage and current, generating from Park and Clarke transformation from AC grid voltage and current for the current inner loop and voltage outer loop control, as high gain PI controller are designed for variable inputs and disturbance caused [24].

2. DESIGN OF AC/DC HMGS

With the revolution of power electronics, converters can extensively distribute active power and reactive power with an additional communication link. Synchronization of voltages and frequency between grid and sources is always challenging. The fluctuations make a major differs in power quality and also raises a serious issue. To overview this a 3-phase H-bridge converter is designed to study the synchronization [25]. A paper on cost efficient PV generation and battery storage system for a MG is implemented with droop controllers [26]. Seamless power transfer in MG is essential for smooth transition between sub grid during islanded conditions the major issues during the transient the recovery time delay which decrease the performance of the grid the direct and indirect control methods are presented to power transfer [27].

2.1. Droop control in HMGS

The concept of droop control differs from the centralized control, the proposed control is linked with real values of droops in terms of voltages, frequency and power. In decentralized control energy sources are independent owners which make simple control, more reliable and easy maintenance. Decentralized droop control is preferred for automatic local information provided without any smart meter-based technology and doesn’t limit its control for any future extensions of sub-grids added to existing system. This system is simple in design and less complex while trouble shooting any of the sub grids.

2.1.1. AC micro grid

Reliable AC grid performs efficiently during overloading and sharing of power is performed with four major parameters active power (P), reactive power (Q), frequency (F), and voltage (V). The change in frequency indicates the load side demands these parameters form a relation which can compare from existence conventional droop control equations.

$$\omega_n = \omega_m + x_m P_m \tag{1}$$

$$U_n = U_m + Y_m Q_m \tag{2}$$

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

Where, ω_m and U_m defines the frequency and voltage at maximum, x_m and y_m are the negative coefficients of droop. Where $P_{ac}(i)$ is the power supplied from AC power source, unit x_{ac} is the droop gain, no.of unit represented by *n*.

2.1.2. DC micro grid

Just like complex AC grid droop control. DC droop control is not associate with complex factor like frequency and reactive power; hence DC droop control becomes comparatively easy task. Eq. (4) defines the DC droop control. Mostly DC power is supplied to telecom industries like data centers with a supplying voltage of 48V. With this option the power conversions from AC power to DC are eliminated, for residential loads mostly LED lights power is supplied from DC sub grids. Figure 2 shows the combined droop characteristics for AC/DC grids.

$$U_{dc,n} = U_{dc,m} + z_m P_{dc,m} \tag{4}$$

$$z_1 s_{dc1} = z_2 s_{dc2} = z_3 s_{dc3} = \ldots\ldots\ldots = z_m s_{dcm} \tag{5}$$

$$P_{load,DC} = \sum_{i=0}^{n} P_{dc}(i) * z_{ac}(i) \tag{6}$$

$P_{dc}(i)$ is power supplied from DC power source and z is droop gain of DC power unit.

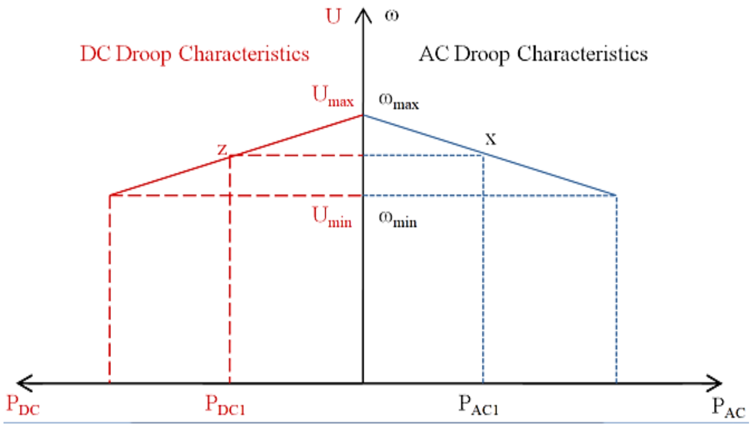

Figure 2. AC/DC droop characteristics

2.2. Interlinking converters

Establishment of ILC has minimized the AC and DC power conversion and also impacted on increased efficiency of the system. The ILC has achieved the autonomous active power sharing in HMGS. The active power sharing among AC and DC grid is dependent of frequency and voltage droops respectively. Islanded model is implemented to verify the performance of Power sharing. The designed ILC is a voltage source converter (VSC) with six switches with capability of bidirectional power flow. ILC are linked and used to share power to AC and DC buses. The direction of power flow of converter decides the nature of converter. If the power is transferred from AC grid to DC grid upon the DC voltage droop leading to increasing the frequency to generate additional AC power there after power shared from AC to DC via converter, then the converter behaves as rectifier and the sign of power is positive. And if the power transferred from DC grid to AC grid upon the frequency droop, then the converter behave as inverter and the sign of power is negative.

3. DETAILED STRUCTURE OF HMGS

HMGS constitute with mainly utility supply, AC MG, DC MG, ILC as shown in Figure 3. DC-capacitor placed in parallel to DC main voltage bus, LCL and LC filter connected at AC side to minimize the voltage ripples and current harmonics and simultaneously electromagnetic interferences. The Table 1 shows the parameter values used to design the HMGS. Phase locked loop (PLL) is used to synchronize the AC grid. Buck and boost converters are used to set the DC voltages. A control technique using a simple PI controller is adopted for power management of MG using PV and ESS [28].

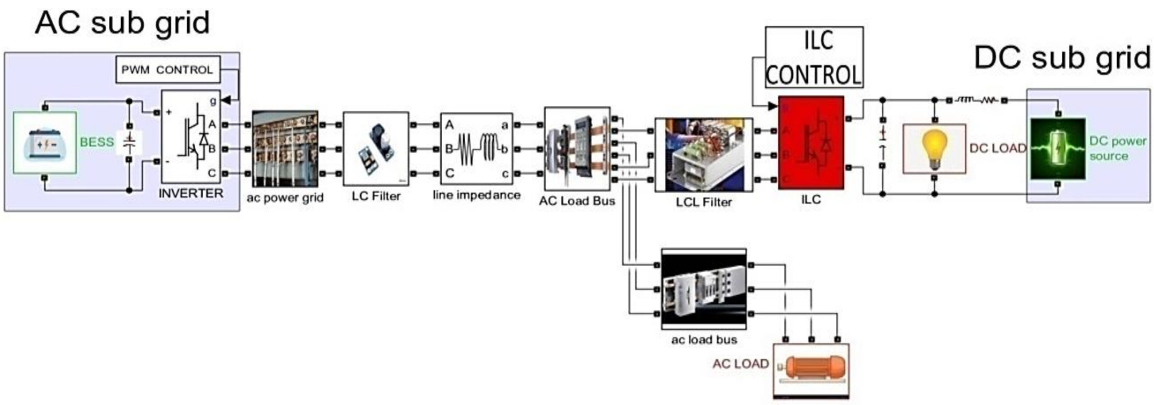

Figure 3. Simulation of AC/DC HMGS in MATLAB/Simulink

Table 1. The parameters of HMGS

AC sub grid	ILC droop control scheme	DC sub grid
AC micro grid voltage, U = 380 V	ILC ref power, $P_{con\ ref}$ = 10k W	voltage, U_{DC} = 800 V
AC Power Generated, $P_{AC\ gen}$ =120 kW	PI Controller-1, KP = 1; KI = 100	Power capacity, $P_{DC\ gen}$ = 45 kW
AC load, $P_{AC\ load}$ =90 kW	PI Controller-2, KP = 20; KI = 30	DC load, $P_{DC\ load}$ = 75 kW
System frequency, ω = 50 Hz	Droop coefficients, x = 0.00025; z = 0.0005	Inductor L = 5 mH
LC filter, L = 5 mH; C = 40 µF	I_{qref} = 0	Capacitor C =2200 µF
Line impedance, R = 0.01 Ω; L = 0.02 mH	ω_0L =1.3188	
LCL filter, L =2,4.2 mH; C = 60µ F	U_{dc-ref} = 800 V	
Capacitor, C = 2200 µF	AC ref. frequency, ω_{ref} = 50 Hz	

Proposed AC sub-grid is integrated with BESS which is connected to inverter for delivering AC power to AC loads. This inverter is controlled by inner loop control by Q/V_{ac}, P_{ac}/F. Outer loop control is designed to obtain autonomous bidirectional power transfer among AC and DC grids which is controlled and maintained by continuously tracking the AC frequency droop and DC side voltage droop. Outer loop control basically utilized for reference signal which are used in inner loop to modulate the voltage. Inner loop control is designed to enhance the performance of controller. Neglecting the losses of converter.

The proposed control architecture shown in Figure 4 is a decentralized modified droop control and its performance depends upon true values of active and reactive power, frequency, DC voltage, DC power. The relation for autonomous power transfer and balancing the power demand on either side of ILC, the modified droop scheme is implemented for converter.

$$(\alpha U - \alpha U_{ref}) + (\beta P_{con} - \beta P_{con\_ref}) - (\gamma\omega - \gamma\omega_{ref}) = 0 \tag{7}$$

The (7) yields the autonomous bidirectional power transfer for the ILC. The performance of converter is more reliable to double closed loop control. The controller performs with reference to voltage and frequency change. The controller limitation can be set by setting the values of α, β, γ. The scaling values for α=0.3, β=0.007, γ=10 is predefined and assumed to be constant. Power converter (P_{con}) performing as rectifier then sign in positive, when performing as inverter signs in negative. In case of load demand on AC load grid will impact on the AC power generation grid, hence forming an equation with power transfer from P_{con} in (8).

$$\delta P_{ac,load} = \delta P_{gen,ac} - \delta P_{con} \tag{8}$$

Frequency droop in general occur when there is change in load demand, this causes change in power generation at AC side which is given as (9).

$$\delta P_{gen,ac} = \frac{-P_{g,ac}}{x}\delta\omega \tag{9}$$

Exchange in active power δP_{con} from AC grid via ILC to DC load side grid is given as (10).

$$\delta P_{con} = -\frac{P_{con}}{x}\delta\omega + \frac{P_{con}}{z}\delta U \tag{10}$$

On substituting (9) and (10) in (8) $\delta P_{ac,load}$

$$\delta P_{ac,load} = \frac{-P_{g,ac}}{x}\delta\omega - \left(-\frac{P_{con}}{x}\delta\omega + \frac{P_{con}}{z}\delta U\right) \tag{11}$$

The (11) explains the variations on frequency and DC voltage due to the change in AC side load demand. When DC load varies the power consumed by DC side load is the sum of power delivered by DC power grid and power transferred by ILC from AC power grid.

$$\delta P_{dc,load} = \delta P_{gen,dc} + \delta P_{con} \tag{12}$$

DC droop defines any differences in DC voltage will impact on its power generated by DC power grid,

$$\delta P_{dc,gen} = -\frac{P_{g,dc}}{z}\delta U \tag{13}$$

Power exchanged in DC load bus due to variation in load is given by (14).

$$\delta P_{dc,load} = \left(\frac{-P_{con}}{x}\right)\delta\omega + \left(\frac{-P_{con}}{z} + \frac{P_{con}}{z}\right)\delta U \tag{14}$$

The results of voltage and frequency during the variations in load demand in AC and DC load bus can be known through the below parameters represented in matrix form (15).

$$\begin{bmatrix}\delta P_{ac,load} \\ \delta P_{dc,load}\end{bmatrix} = \begin{bmatrix}\frac{-\mathrm{P_{g,ac}}}{\mathrm{x}}\ \frac{P_{con}}{x} & \frac{P_{con}}{z} \\ \frac{-P_{con}}{x} & \frac{-P_{con}}{z} + \frac{P_{con}}{z}\end{bmatrix} * \begin{bmatrix}\delta\omega \\ \delta U\end{bmatrix} \tag{15}$$

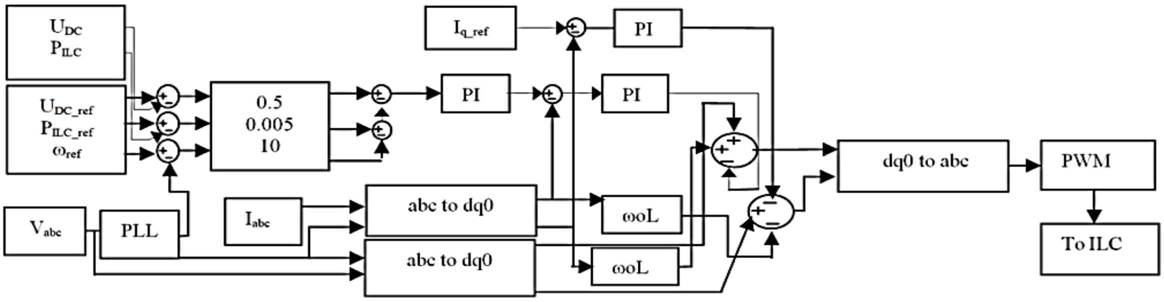

Figure 4. Control architecture bi-directional power flow through interlinking converter

4. RESULTS AND DISCUSSION

AC/DC HMGS is designed and simulated in MATLAB/Simulink for various test cases in Islanded mode. A similar paper is presented on HMGS for the reliability and stability of interlinking converters with power flow analysis during the steady state condition [29]. It has been noticed that due to coupling of DC voltage and AC system frequency the result might be slightly differing. A PV connected inverter is controlled by adaptive hysteresis band current controller the benefit compare to conventional control this provide the constant switching frequency [30]. The AC power grid is 120 kW of capacity, the AC loading capacity of 90 kW. The DC power grid is of 45 kW capacity and the load capacity of 75 kW. AC voltage is maintained to 380 V and DC bus voltage is 800 V. The set voltage range is ±5% and ±3% for frequency. Three controller scaling factors are considered for autonomous operation. The frequency droop of the converter is 0.00008 and DC voltage droop is 0.0006. A paper on inter connected of grids is presented to overview the future of MG with RES, this grid operates on the demand curves and share the power accordingly [31]. Scheduling the power generation and loads according to the power curves this EMS adopts multi agent system techniques which functions on distributed artificial intelligence providing less complex system, more flexible system [32].

4.1. ILC performs as rectifier

AC MG generates 50kW of power, t=0-1 sec the AC load grid consume 40 kW of power and the remaining 10 kW of power is transferred to DC load grid. As power generated by DC power grid is of 5 kW and the load demand is of 15 kW the gradual decrease in DC voltage to 790 V the power is delivered by AC power grid by increasing its power generation and droop is given by (11). The variation in frequency is observed in Figure 5. The increase in DC power demand in autonomous operation decrease the AC frequency by 0.1 Hz. At t=1 sec DC load increase to additional 60 kW of power as shown in Figure 6 and the voltage is decreased to 780V as shown in Figure 7. As DC power doesn't generate any power the complete 60 kW of power is shared from AC source via ILC.

4.2. ILC performs as inverter

The converter has the capability to regulate with AC and DC droops making converter to operate in bidirectional mode at time t=1.6 sec AC active power load is increase to 50 kW as shown in Figure 8. As the AC power grid is already generating 110 kW and can generate a maximum of more 10 kW. Due to this load demand frequency is decreased by 0.1 Hz. During this mode the DC power generation is increased to additional 40 kW of power and is transferred to AC load grid via ILC and hence the power sign is negative which indicate the converter is behaving in inversion mode. Performance of ILC as rectifier and inverter is shown in Figure 9. It has been analyzed AC MG is more responsive to the AC droop coefficients during the inversion mode for the stability issues.

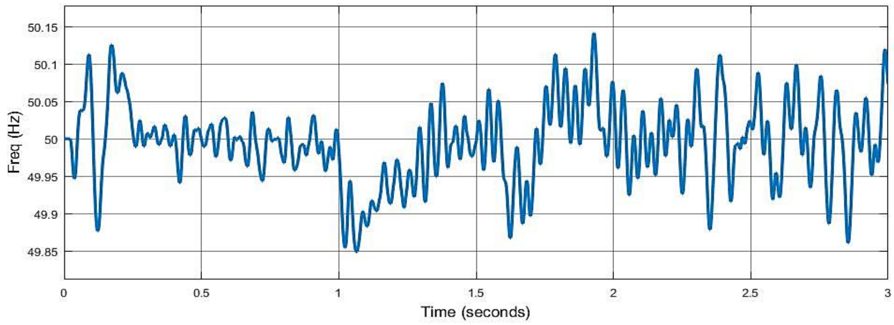

Figure 5. Frequency variations

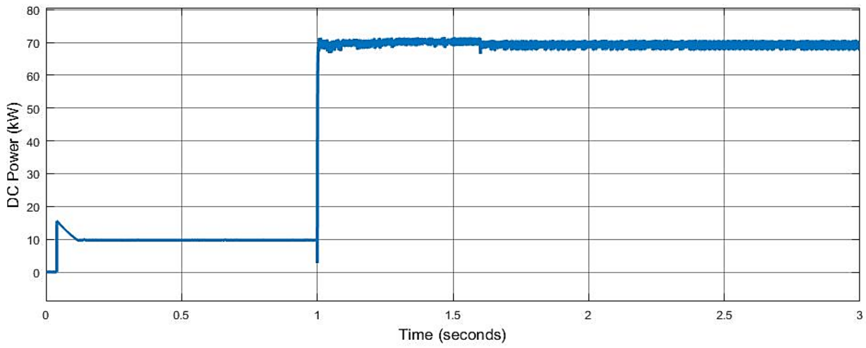

Figure 6. DC loads power

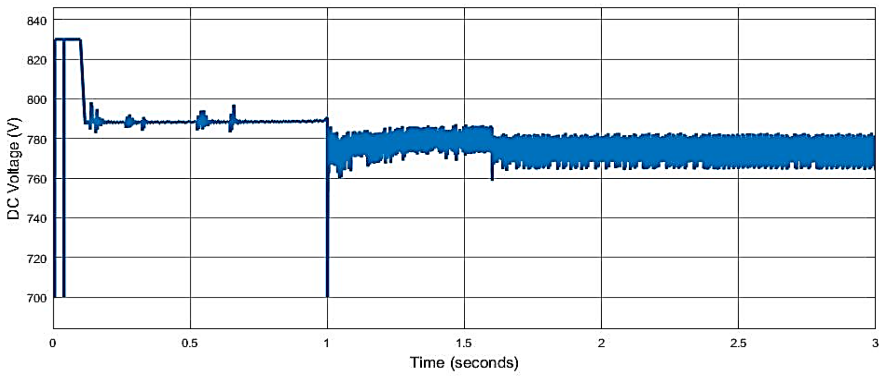

Figure 7. DC Voltage variations

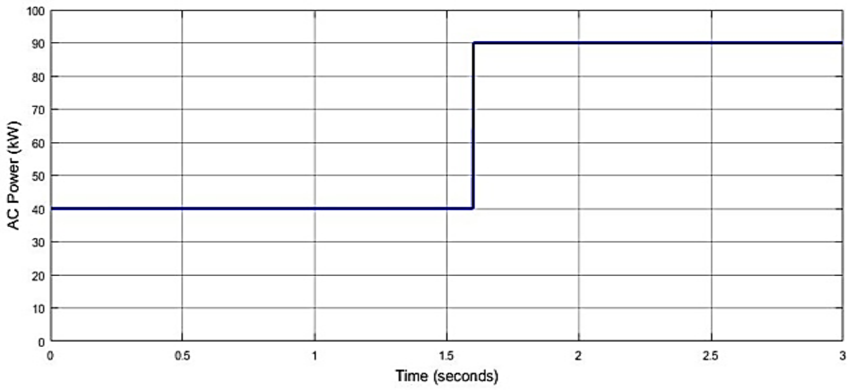

Figure 8. AC loads power

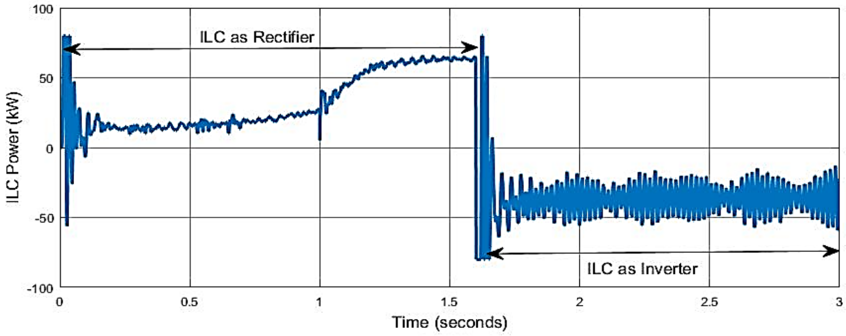

Figure 9. ILC Power sharing in HMGS

5. CONCLUSION

In this paper autonomous bidirectional power sharing to AC/DC sub-grid connected to HMGS is achieved via ILC with a novel decentralized droop control scheme. Based on the droops of voltage, frequency and power the ILC control is designed to transfer power bidirectional to either side of the AC/DC grids during islanded and overloading conditions. This control scheme creates a simple matrix for load change in AC and DC side which identifies the impact on voltage and frequency. This scheme provides the default power management of power transfer through the ILC without any communication link. The control of ILC is simple in design, robust, eliminates the frequency deviations, stabilizes the voltage, reduces the circulating currents, accurate power transfer and improves the transient response time. This designed control for ILC helps in reducing number of power converters, adds a plug and play feature to MG.

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BIOGRAPHIES OF AUTHORS

Syed Abdul Razzaq is a Research Scholar in Electrical and Electronics Engineering Department at the 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 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 is Prof. in Electrical & Electronic Engineering Department and Dean-Electrical School of 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 area of interest is in High voltage engineering, Power System Voltage Stability, Converters and Renewable Energy Sources. He can be contacted at email: deansoe@veltech.edu.in.