Hybrid Microgrid: Energy Management under Different Loading Condition using Typhoon HIL’s Real-time Digital Simulator

Ruchi Verma¹*, Hemant Kumar Verma¹, Priyanka Verma¹
¹Electrical Engineering, Department (PSE), Shri Shankaracharya Group of Institution, Junwani, Bhilai, Chhattisgarh, India.

E-mail: ruchiverma150196@gmail.com

Abstract. This paper presents real time simulation of hybrid microgrid consist AC microgrid along with DC microgrid and utility grid, where developed Hill Climbing algorithm for even power transfer between AC microgrid plus DC microgrid ensuring stable and reliable system operation under different loading conditions. Also generalized function generated to deal with the power flow from utility grid to AC microgrid and DC microgrid. Typhoon HIL control centre used for the accomplishment of hybrid microgrid. The proposed system is developed in the Schematic Editor. Hybrid microgrids are simulated using the real-time emulator HIL402 for real-time simulation within the SCADA environment.

Keywords: Hybrid micro grid, power flow management, hill climbing, interlinking converter, real-time simulation, Typhoon HIL.

1. Introduction

Due to concern of global warming phenomenon and integration of environmental issue and carbon emission lead to progressive amalgamation of distributed renewable resources in power networks. This area rapid growth increases interest in microgrid concept. Microgrid is group of electrical sources such as distributed energy resources, loads and storage connected with utility system grid system to supply power in rural areas. It operates as controllable system which can function in grid tied mode in addition to island mode [2], [3].

Microgrids can classify in three types AC, DC and hybrid micro grid according to its type of connection. Among all three types, hybrid microgrid is most convenient as it consist advantage of AC as well as DC microgrid. Hybrid microgrid incorporates AC plus DC distributed units, storages and both AC and DC loads, for power conversion, incorporates interlinking converters. According to connection to the bus Hybrid micro grid can categorize in three types hybrid AC coupled microgrid, hybrid DC coupled microgrid and hybrid AC DC microgrid. Hybrid AC DC microgrid consist advantage of AC coupled and DC coupled microgrid together. Figure.1 demonstrates the classic hybrid AC DC microgrid block diagram [4], [5].

Hardware-In-the-Loop (HIL) system is laboratory technologies which allow real-time simulation within the software to a power converter or undersized electrical power system, at the same time it can interfaced with any real laboratory hardware. This accumulates time as well as money on the choice of hardware components in addition to the structure from scratch.

The merging of ICs improves system reliability and power quality [7], [9]. Uses of ICs are responsible for voltage and frequency regulation in whichever services. Endow with active-reactive
power control to reach appropriate power division in together grids tied and untied mode of operation with optimized operating cost [5].

The power allotment among each connected system need a proper management of energy according to load demand. Voltage and frequency stability in microgrids in AC DCs should be maintained whether its grid tied or island mode. Therefore, a finest power control must be performed to offer sufficient power sharing among devices. Various literatures have been classified control strategies in the primary, secondary and tertiary. Primary control level concluded droop based techniques are most preferable for both operating modes [10], [11]. Secondary level classified into two strategies centralized and decentralized. For low scale micro grids centralized strategies are more useful, whereas decentralized ones are suitable for multiple users with large scale system. In tertiary level strategy centralized approaches are more common than decentralized ones [10]. In [1] discussed a new hill climbing power flow algorithm in which the verdict to prevent the perturbations is based on condition $f_{pu} \approx V_{dc, pu}$ to stop the perturbation. This facilitates proportional power sharing in AC also DC sub grids.

Proportional integral (PI) controllers in hybrid microgrids are extensively used in the old days; several papers have discussed drawbacks of PI controllers. In [15] compared various adaptive controlling methods like fuzzy logic, bacterial search algorithm etc. also stated that change in operating point is a critical issue in micro grids which can be handle by using intelligent optimization algorithms and adaptive control techniques which increase the interest for adaptive control methods. Some literature shows comparison between perturb and observe algorithm and hill climbing algorithm, and due to straightforwardness, easy implementation and low down cost with faster response than P&O; hill climbing algorithm is more suitable [16], [17]. In [12],[14] elaborated about controlling hybrid AC/DC microgrid which involves energy storage and renewable energy with pulsed loads. Explained about modelling of the AC/DC Hybrid Microgrid.

A quicker manner to certify research proposals, is expected to be complementary related to microgrid modules and requires further control approaches to operate under an envelope command. Thus, the environment near the real world stands as an important obligation to build up, test and make lawful solutions for such purpose. To provide the system with each reimbursement related to microgrid approach. Therefore real-time simulation can help to establish an adequate test-bed to accelerate researches and innovations.

In literature [6] presented the real-time simulation technologies as well as their relativity to smart-grid approaches and the progress of real-time simulators, industrial as well as educational backgrounds are outlined and its current confronts are pointed. Also stated characteristics of Typhoon HIL, in which numerous processors operate in corresponding to match the marked stage at simulation runs and a host computer is placed to organize the model off-line; then compiled and loaded onto the target platform also for monitoring the results of the simulation.

[8] Presents a master / slave communication-based power management system to include PV and energy storage systems, meant for a real-world grid-interactive hybrid microgrid. For the implementation of the microgrid Typhoon HIL Control Centre is in employment with SCADA interface and the power management system.
On basis of Electrical Engineering Related tools and modelling advantage of Typhoon HIL’s Virtual HIL device over other Simulation Software are as follows [18]:

It uses its own model editor developed for real time simulation and no need of third party software so no complication of integration with third party tool.

Typhoon uses FPGAs as the computational platform to achieve the precision in time from 500 nano second to 20 micro second. There is no need to develop first offline model and then retransforming the same in to real time.

Controller board programmed using any third party tool like MATLAB, PSCAD, ETAB, PSIM etc. can be interfaced directly with HIL Simulator. Hence closed loop testing platform can be created.

In the proposed work, a hybrid micro grid system is proposed which contain both AC and DC sources connected with utility grid through ICs. The system serves to both AC and DC load demand. For power flow control in ICs for sub grids a new hill climbing algorithm is applied. The power sharing under different loading conditions managed by applying generalized function. The software model is developed in Typhoon HIL schematic editor inside the SCADA environment and interfaced with Real–time emulator HIL402. The remains are structured as follow. Section II give explanation modelling and configuration of the system. The power flow of the system discussed in section III. The real time simulation with case study in session IV. Result and discussion presented in section V. session VI concluded the presented work.

2. Hybrid Microgrid Modelling and Configuration

Here considering a micro grid system which consist AC and DC sub grids both interlinked to AC main grids. There are ICs are placed for power division among the grids and sub grids. The hybrid microgrid configuration show in Figure 2 A DC sub grid contains DC source and DC loads connected with AC sub grid containing AC source and AC load through bidirectional converter. Both AC plus DC sub grid also connected to AC main grid through ICs as shown in Figure 2.

The electrical diagram of system exposed in Figure 3 Diagram consist main grid bus \(V_{abc\text{, main}}\) and \(I_{abc\text{, main}}\) are main grid voltage and current respectively. There are three interlinking converters are connected, first IC is regular conventional 6 bridge converter connected between utility grid along with DC sub grid named as IC1 in diagram. Second converter IC2 is AC-DC-AC five pulse converter, connected between DC sub grid and AC sub grid. There is control circuit box which controls the entire interlinking converters. The last one is IC3 connected between AC sub grid and main utility grid, which is a 3×3 Matrix converter or 5 pulses AC-DC-AC converter. The current direction changes according to loading conditions.

![Figure 2 Block diagram of inter connection of hybrid micro grid.](image)

The last one is IC3 connected between AC sub grid and main utility grid, which is a 3×3 Matrix converter or 5 pulses AC-DC-AC converter. The current direction changes according to loading conditions.
DC source droop characteristic specified as follow:

\[ V_{dc} = V_{dc,\text{max}} - n_{dc}P_{dc} \]  

(1)

Where \( n_{dc} \) is droop coefficient, \( V_{dc,\text{max}} \) is maximum value of DC source, \( P_{dc} \) output power from DC source. AC droop characteristic for voltage also frequency is:

\[ V_{m} = V_{m,\text{max}} - n_{acv}Q_{ac} \]

(2)

\[ f = f_{\text{max}} - n_{acf}P_{ac} \]

(3)

Where \( n_{acv} \) is voltage and \( n_{acf} \) is a frequency droop coefficient respectively, \( V_{m,\text{max}} \) is maximum voltage from AC source and \( f_{\text{max}} \) maximum permissible frequency. \( P_{ac} \) and \( Q_{ac} \) are active along with reactive powers of ac source respectively.

The interlinking converter (IC\textsubscript{DC-AC2}) model is mathematically expressed as:

\[ V_{a2,\text{IC}} = m \frac{V_{dc}}{2} \sin(\theta + \delta) \]

(4)

\[ V_{b2,\text{IC}} = m \frac{V_{dc}}{2} \sin(\theta + \delta - \frac{2\pi}{3}) \]

(5)

\[ V_{c2,\text{IC}} = m \frac{V_{dc}}{2} \sin(\theta + \delta + \frac{2\pi}{3}) \]

(6)

The voltage of three phases a,b,c are expressed as equation (4) & (6). Where \( V_{a2,\text{IC}}, V_{b2,\text{IC}} \) and \( V_{c2,\text{IC}} \) are IC voltages and \( \delta, \theta \) and \( m \) are power angle, instantaneous angle and modulation index respectively.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{hybrid_micro_grid_system_model.png}
\caption{Electrical diagram of hybrid micro grid system model.}
\end{figure}

In IC\textsubscript{DC-AC2}, hill climbing power flow algorithm is applied for controlling action of IC as shown in flow chart in Figure 4. Fast subroutines quickly determine instantaneous values of power angle and modulation index. And also called when the system observe any change in values. The HC subroutine performs perturbation in power angle.
After finishing perturbation, control transferred to Steady state where values of frequency as well as voltage are monitored. The parameters of main grid voltage, dc voltage from DC sub grid and power transferred across sub grids.

In Fast sub routine using feature scaling which is procedure to regularize variables within certain range, value of frequency and DC voltage converted into per unit values. In algorithm value of frequency and DC voltage ranged between -1 to 1.

![Flow chart used for Hill Climbing algorithm](image)

**Figure. 4** Flow chart used for Hill Climbing algorithm

For the other ICs there is a MATLAB function generated for power sharing among AC sub grid, AC main grid and DC sub grid explained in section 3.

### 3. Methodology Power Flow Analysis of Hybrid Microgrid

In the energy system the power management is very important task to make available power according to system load demand without any time delay. In the proposed system the MATLAB function designed to grant power to each load and keep power balance in system. The whole process for IC control shown as flow chart in **Figure. 5**. The flow chart represents different loading conditions and control response of interlinking converter according to the loading conditions.

Function for main grid through which the power sharing is controlled is explained further. The activation function have a condition when input power for IC is greater than zero equation (11) then power from main grid transferred to DC micro grid. The amount of power will be calculated by equation (12). From equation (11), (12) and (13) $P_I$, $P_{main}$, $P_{ac}$, $P_{dc}$ denotes power transfer from IC, main grid, AC micro grid and DC micro grid respectively. $AC_{load}$ and $DC_{Load}$ denotes AC and AC power demand.

\[ P_I > 0 \]  \hspace{1cm} (11)
\[ P_{\text{main}} = DC_{\text{load}} - P_{\text{dc}} - P_I \]  

(12)

\[ P_{\text{main}} = AC_{\text{load}} - P_{\text{ac}} - (-1 \times P_I) \]  

(13)

This will enable power transfer from main grid to AC micro grid. When IC shows zero power it means load supplied from micro grids. There is no need to flow power from main grid. It means the power is flowing in normal condition. In this way the power flow control is performed.

**Real-time Simulation and Case study**

**HIL simulation**

The proposed model embraces the emulator hardware and application software that supports a diversity of model configurations. As result of circuit compiler the circuit parameters could be easily modified. To illustrate the model to be simulated in real time circuit compiler consist of a schematic editor and software to facilitate by compiling the model description into instructions for the processor. In simulation the hybrid micro grid average model is designed in schematic editor. In the proposed model the value of AC source rated 10 kW with frequency range between 49Hz to 51Hz. The DC source value rated at 10 kW along with DC voltage ranging between 590V to 615V. The interlink converter ranged up to 5 kW it means it can share power only under the range. There are some cases simulation studies carried out with different loading conditions in SCADA environment.

**Real time implementation**

The system hardware is simulated in real time HIL platform. The model of the hybrid microgrid is simulated using an HIL402 emulator. **Figure.6** shows the experimental setup.

In each one switching period system has to perform the following tasks:

- Hardware is connected to the computer where the hybrid microgrid model is developed in Typhoon HIL software/ schematic editor. Hardware HIL402 measures the input signals according to it creates real time environment for microgrid system.
- The system works in real time environment. The hardware consist bidirectional programme for input and output. After running the model output signals will show in SCADA panel.
- The signals shown in SCADA are real time simulation results. From SCADA panel the parameters can be changed and vary as per requirement.
Figure. 6 Experimental hardware setup

HIL experimental results

In hardware part model is connected to HIL402 emulator for real time simulation. Typhoon HIL402 environment permit for extraordinary control of active as well as reactive power flow, current harmonics along with grid voltage sources with arbitrary magnitude, phase and frequency.

Case 1

At case 1 all the loads are constant. Where AC and DC loads are rated up to 5 kW as exposed in Figure. 7. In Figure. 7(a) and 7(b) shows AC and DC load demand. Figure. 7(c) shows micro grid power $P_{ac}$. Figure. 7(d) shows DC micro grid power $P_{dc}$ and Figure. 7(e) shows main grid power $P_{ac\_main}$ respectively. Figure. 7(f) shows power output of IC.

Figure.7 Output values with constant load (a) AC load and (b) DC load, (c) AC microgrid power, (d) DC microgrid power, (e) main grid power and (f) power transfer through IC.
**Figure. 7** shows event in 1 when both loads are constant rated at 5kW. AC micro grid, DC micro grid both generating 5kW power and completing load demand by own generation, therefore no power supplying from main grid and IC, both shows 0 power.

**Case 2**

Inside case 2 AC load is 15 kW and DC load is 5 kW as shown in **Figure. 8**. In **Figure.8(a)** show AC and (b) DC load demand. (c) Shows power output from AC micro grid power $P_{ac}$ 9 kW, DC micro grid power $P_{dc}$ 10 kW and main grid power $P_{ac,main}$ 1 kW. Power output through IC is 5 kW and –ve sign shows power transferring from DC microgrid to AC load.

![Graph](attachment:image1.png)

**Figure. 8**. Output values with variable load (a) AC load, (b) DC load, (c) AC microgrid power, DC microgrid power, main grid power and power transfer through IC.

**Case 3**

In case 3 AC load is 15 kW and DC load is 10 kW as show in **Figure. 9**. In **Figure. 9(a)** shows AC and (b) DC load demand. (bc shows power output from AC micro grid power $P_{ac}$ 9 kW, DC micro grid power $P_{dc}$ 10 kW and main grid power $P_{ac,main}$ 5 kW. Power output through IC is 5 kW and –ve sign shows power transferring from DC microgrid to AC load.

![Graph](attachment:image2.png)
Figure. 9 Output values (a) AC load and (b) DC load, (c) AC microgrid power, DC microgrid power, main grid power and power transfer through IC.

Case 4
In case 4 AC load is 10 kW and DC load is 5 kW as revealed in Figure. 10. In Figure. 10(a) shows AC and (b) DC load demand (c) Shows power output from AC micro grid power $P_{ac}$ 5 kW, DC microgrid power $P_{dc}$ 10 kW and main grid power $P_{ac\_main}$ 0 kW. Power output through IC is 5 kW and –ve sign shows power transferring from DC microgrid to AC load.
Figure 10 Output values (a) AC load and (b) DC load, (c) AC microgrid power, DC microgrid power, main grid power and power transfer through IC.

Case 5

In case 5 AC load is 5 kW with DC load is 15 kW as exposed in Figure 11. In Figure 11(a) and 11(b) shows AC and DC load demand. Figure 11(c) shows power output from AC microgrid power $P_{ac}$ 10 kW, DC microgrid power $P_{dc}$ 10 kW and main grid power $P_{ac\_main}$ 0 kW. Power output through IC is 5 kW and –ve sign shows power transferring from AC microgrid to DC load.
Figure 11: Output values (a) AC load and (b) DC load, (c) AC microgrid power, DC microgrid power, main grid power and power transfer through IC.

**TABLE I**

**EVENTS DURING DIFFERENT CASES**

| Case | Loading Conditions | Change in power |
|------|-------------------|-----------------|
|      | AC Load (KW) | DC Load (KW) | $P_{dc}$ (KW) | $P_{ac}$ (KW) | $P_{ac\_main}$ (KW) | $P_I$ (KW) |
| 1    | 5              | 5              | 5              | 5              | 0               | 0          |
| 2    | 15             | 5              | 10             | 9              | 1               | -5         |
| 3    | 15             | 10             | 10             | 9              | 5               | -5         |
| 4    | 10             | 5              | 10             | 5              | 0               | -5         |
| 5    | 5              | 15             | 10             | 10             | 0               | 5          |
Table 1 shows events during different loading cases. The power management according to load is successfully done by three sources AC, DC micro grid and main utility grid. All ICs performing synchronously as per load demand weather its constant or variable.

4. Result and discussion

The purpose of presented paper is to perform real time power management within hybrid micro grid via hill climbing algorithm. In this system consist more complex structure and there is another function for power flow the whole system is developed in real time environment using HIL402 hardware. In our system power flow manage among AC micro grid, DC micro grid, main grid with AC load, DC load, different loading conditions which is more complex. Now challenge is hill climbing algorithm has to work to manage power among three sub grid system and it is performing that. Hence, this paper shows the accessibility of hill climbing with large, complex system and also synchronized work with other functions also incorporates benefits of Typhoon HIL real time emulation.

5. Conclusion

In this paper, in real time environment a coordinated control of hybrid micro grid is presented. There are two sub grid systems AC grid and DC grid system, called as sub grid system. Both connected with AC main grid called as utility grid. Both sub grids are interlinked with interlinking converter where Hill climbing control algorithm is applied for proportional power division in AC along with DC sub grids. To control power flow from utility grid a generalized function is generated. To investigate and verify the system a generalized Typhoon HIL software model is developed in HIL SCADA environment. To show the system power flow different loading conditions are made and the simulated model is emulated in HIL402 and results are observed which validated the performance of the control strategy.

References

[1] O. Khan, S. Acharya, M. Al Hosani and M. S. El Moursi. 2018. Hill Climbing Power Flow Algorithm for Hybrid DC/AC Microgrids. IEEE Transactions on Power Electronics, Volume: 33, 5532 - 5537.
[2] Ander Ordone, Eneko Unamuno and Jon Andoni Barrena. 2019. Interlinking converters and their contribution to primary regulation: a Review. Electrical Power and Energy Systems 111, 44-57.
[3] Saroja Kanti Sahoo, A. K. Sinha and N. K. Kishore. 2018. Control Techniques in AC, DC, and Hybrid AC-DC Microgrid: A Review. IEEE Journal of Emerging and Selected Topics in Power Electronics, Volume: 6, 738 – 759.
[4] Eneko Unamuno and Jon Andoni Barrena. 2015. Hybrid ac/dc microgrids—Part I: Review and classification of topologies. Renewable and Sustainable Energy Reviews 52, 1251-1259.
[5] Quan Zhou, Mohammad Shahidehpour and Zhiyi Li. 2019. Two-Layer Control Scheme for Maintaining the Frequency/Voltage and the Optimal Economic Operation of Hybrid AC/DC Microgrids. IEEE Transactions on Power Systems, Volume: 34, 64 - 75.
[6] Luis Ibarra and Antonio Rosales. 2017. Overview of Real-Time Simulation as a Supporting Effort to Smart-Grid Attainment. Energies, 10(6),817.
[7] Lihu Jia, Yongqiang Zhu and Shaofei Du. 2018. Analysis of the Transition between Multiple Operational Modes for Hybrid AC/DC Microgrids. CSEE Journal Of Power And Energy Systems, Volume: 4, 49 – 57.
[8] Hooman Ekhteraei Toosi, Adel Merabet.2019. Central Power Management System for Hybrid PV/Battery AC-Bus Microgrid Using Typhoon HIL. IEEE 28th International Symposium on Industrial Electronics (ISIE), Canada, 10.1109/ISIE.2019.8781277.
[9] Ajay Gupta, Suryanarayana Doolla and Kishore Chatterjee. 2017. Hybrid AC-DC Microgrid: Systematic Evaluation of Control Strategies. IEEE Transactions on Smart Grid, Volume: 9, 3830 - 3843.

[10] Eneko Unamuno and Jon Andoni Barrena. 2015. Hybrid ac/dc microgrids-Part II: Review and classification of control strategies. Renewable and Sustainable Energy Reviews 52, 1123-1134.

[11] Josep M. Guerrero, Juan C. Vasquez and José Matas. 2011. Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization. ieee Transactions On Industrial Electronics, Volume: 58, 158 - 172.

[12] Tan Ma, Mehmet Hazar Cintuglu and Osama Mohammed. 2015. Control of Hybrid AC/DC Microgrid Involving Energy Storage, Renewable Energy and Pulsed Loads”, IEEE Industry Applications Society Annual Meeting, 10.1109/IAS.2015.7356857.

[13] Peng Wang, Chi Jin and Dexuan Zhu. 2014. Distributed Control for Autonomous Operation of a Three-Port AC/DC/DS Hybrid Microgrid.IEEE Transactions on Industrial Electronics, Volume: 62, 1279 - 1290.

[14] Hao Zheng, Hongwei Ma and Kaiqi Ma. 2017. Modeling and Analysis of the AC / DC Hybrid Microgrid with Bidirectional Power Flow Controller. China International Electrical and Energy Conference (CIEEC), 25-27.

[15] Magdi S. Mahmoud and Nezar M. Alyazidi. 2017. Adaptive intelligent techniques for microgrid control systems: A survey. International Journal of Electrical Power & Energy Systems, Volume 90, 292-305.

[16] Sabah B. Siad and Ahmad Malkawi. 2019. Nonlinear control of a DC MicroGrid for the integration of distributed generation based on different time scales. International Journal of Electrical Power & Energy Systems, Volume 111, 93-100.

[17] Fangrui Liu, Yong Kang, and Yu Zhang .2008. Comparison of P&O and Hill Climbing MPPT Methods for Grid-Connected PV Converter. 3rd IEEE Conference on Industrial Electronics and Applications, Singapore, 10.1109/ICIEA.2008.4582626.

[18] Ruchi Verma and Hemant Kumar Verma. 2019. Hybrid Microgrid: Energy Management under Different Loading Condition. I-Manager’s Journal on Power Systems Engineering: Nagarkoil Vol. 7, Iss. 3, 36-44.

[19] R. Swarnkar, H. K. Verma and R. N. Patel. 2019. Comparative Analysis of Isolated and Non-Isolated Bi-Directional DC-DC Converters for DC Microgrid. 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), NOIDA, India, 2019, pp. 557-562.

[20] Microgrid Testbed. Available online: https://www.typhoonhil.com/doc/brochures/Typhoon-HIL-and-SPS-Microgrid-Testbed.pdf.