International Journal of Engineering & Technology, 7 (4.44) (2018) 1-7

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Novel Design of Energy Management and Control for Smart Microgrids in Urban Buildings

Y. V. Pavan Kumar

School of Electronics Engineering, Vellore Institute of Technology - Andhra Pradesh (VIT-AP) University, Amaravati-522237, Andhra Pradesh, INDIA
**Corresponding author E-mail: pavankumar.yv@vitap.ac.in*

Abstract

Microgrids are becoming a popular way to cater the sustaining power needs of urban community loads as buildings of financial districts, universities, industrial zones, gated communities etc. Effective utilization of available energy resources and smart management of operating loads will increase level of supply reliability and reduces the utility grid dependency. With this intent, this paper proposes an original philosophy of designing Smart Energy Management and Control (SEMC) algorithm to transform microgrids as smarter grids. Building microgrid system is modeled using MATLAB/Simulink and is interfaced with real time controller via data acquisition system to form Hardware In the Loop (HIL) setup. This real time controller is realized through Programmable Logic Controller (PLC) by using SEMC algorithm. SEMC manages the available energy sources as well as operating loads based on their availability and priority to supply the total instantaneous load on the microgrid. The proposed algorithm can also facilitate utility grid interaction for import and export of power in deficit and excess available power conditions respectively. From the implementation of the proposed algorithm, the obtained results show that the proposed system ensures reliable and stable supply to building loads.

Keywords: *Grid Exchange Unit (GEU); Hardware in the Loop (HIL); Programmable Logic Controller (PLC); Renewable Energy Sources (RES); Smart Energy Management and Control (SEMC)*

1. Introduction

The study on microgrids is fundamentally focused to meet the electrical energy needs of the people live in remote areas to where the enhancement of the utility grid is uneconomical [1]. In the recent years, due to the more urbanization, the focus has been shifting towards the urban energy sector. Especially, in the developing regions/countries, the rate of demand growth is more than supply growth, which leads to regular grid failures. There are many drives to design integrated and synergetic microgrids with economic and ecological benefits to reduce burden on the utility. But, the ecological dependent local RES may not guarantee the stable power all the time. Hence effective use of available energy sources is required to improve the system reliability [2]-[4].

There were many literature works discuss about the management of available energy sources based on the use of hybrid energy concept [5]-[8], real-time HIL control setups [9]-[15], multiagent control methods [16], [17], artificial intelligence and machine learning methods [18]-[22]. Apart from these, voltage/frequency control strategy was proposed in [23], which helps the microgrid to be an active network in the overall utility grid operations. This method helps in penetration of higher concentration of renewable energy and facilitates lower cost management of available energy sources. However, this method is developed only for the local energy management. A centralized control approach, which takes care of utility grid level was not considered in the developed algorithm. Similarly, the control of dynamic nature of integrated energy with wind power system and diesel generator system, which is supplying microgrid loads during various disturbances and uncertainties was discussed in [24]. The key shortcoming of this method is, the major focus on the voltage and frequency control in the islanded microgrid becomes very dependent without which management of microgrid energy sources is not possible.

The formation of a microgrid architecture with central DC bus, independent DC-to-DC power converter for each power source, and common DC-to-AC power inverter was discussed in [25]. This architecture requires more number of converters, which increases cost of the deployment. The increase in number of conversions also affects the power quality of the system. A modular, scalable, and flexible microgrid architecture and its control scheme was presented in [26]. Two droop control functions were considered for the controller implementation. The advantage of this method is, when grids operate in parallel, they can support each other in the event of failure. But, the internal protection of various microgrids has not been considered which may affect the power sharing among multiple microgrids. Similarly, a hierarchical control scheme using wireless technology for microgrids was presented in [27]. A rational balance between battery usage and generation was argued with the help of an energy management system design. However, the control strategy was established for island mode only, but not for the grid connected mode.

Majority of the methods given in the literature discuss about the management of available energy sources. Apart from this, the management of available load can also play a key role in the economic operation of microgrids. Besides, as per the directions given in the Indian smart grid roadmap vision document, utilization of available energy resources and priority based load management are the foremost challenges in the deployment of smart microgrids [28]. The traditional microgrid shall have additional layers of plant control, automation, and communication to transform it to smarter. As a whole, it is seen that these systems need more research in providing stable and reliable power to local loads by proper utility interaction, effective energy management by resource and load management as per IEEE-1547 and IEC-61850/970 guidelines.

In view of all the aforesaid issues, this paper proposes a novel design of energy management and control unit for operating the available energy sources and loads effectively to leverage microgrids as smarter girds. For the implementation of the proposed method, HIL based novel laboratory setup is developed to manage the energy sources and loads in an urban community microgrid.

2. Proposed System Description

The proposed HIL setup for smart energy management and control in microgrids is shown in Fig. 1. It is divided into two sub systems, namely, microgrid model in MATLAB/Simulink and SEMC unit, which are explained as follows.

2.1. Sub-system-1: Microgrid Model in Simulink

Photovoltaics (PV), fuel cells (FC), and wind power (WP) are taken as the available energy resources that are coupled to DC bus by respective local controller (LC) in the microgrid as shown in Fig.1. This DC bus is further interfaced to AC bus using DC-to-AC power inverter. This AC bus is interfaced with utility grid via GEU, which performs bi-directional action based on the SEMC command; one in onward direction for power export and other in reverse direction for power import based on excess and deficit power conditions. The GEU constitutes a circuit breaker and transformer operating on 11kV (HV) and 440V (LV) to meet the required voltage levels on both sides. GEU is 'ON' for grid import or export modes and 'OFF' for islanding (sufficient power/faults).

2.2. Sub-system-2: SEMC Unit

A novel algorithm SEMC is proposed for real time energy management and control of microgrid. It manages available resources to meet instant load. The excess or deficit power is handled by utility grid by operating GEU. PLC is used to realize proposed SEMC logic in real-time using IEC 61131-3 programs such as Ladder diagram (LD), Structured text (ST), etc.

2.3. Overall System Connection

The microgrid architecture modeled in sub system-1 is loaded into xPC target using Ethernet or RS232 interface as shown in Fig. 1. This xPC target model is connected to PLC to perform HIL testing. Peripheral Connect Interface (PCI) based Data Acquisition (DAQ) boards and relay circuitry is used to connect xPC target PC to PLC. As voltage levels of PLC (24V) and PCI (5V) are different, to match these, normally open (NO) and normally closed (NC) relays are used for digital signal communication between DAQ and PLC.

3. Microgrid System Modeling

The basic units of the microgrid - PV, FC, WP with their battery banks are modeled as per [29]-[32]. Other models are given below.

3.1. Load Arrangement

The building load is modeled as primary/priority and secondary, where, priority load demands continuous supply at all the time and secondary load is controllable based on energy availability. The secondary load is activated (ON) during excess power or if power drawn from utility grid satisfies the maximum contracted demand limit and is deactivated (OFF) during power deficit or power import limit violation conditions. Secondary load is further divided into sub-loads to obtain smooth transition during load shedding.

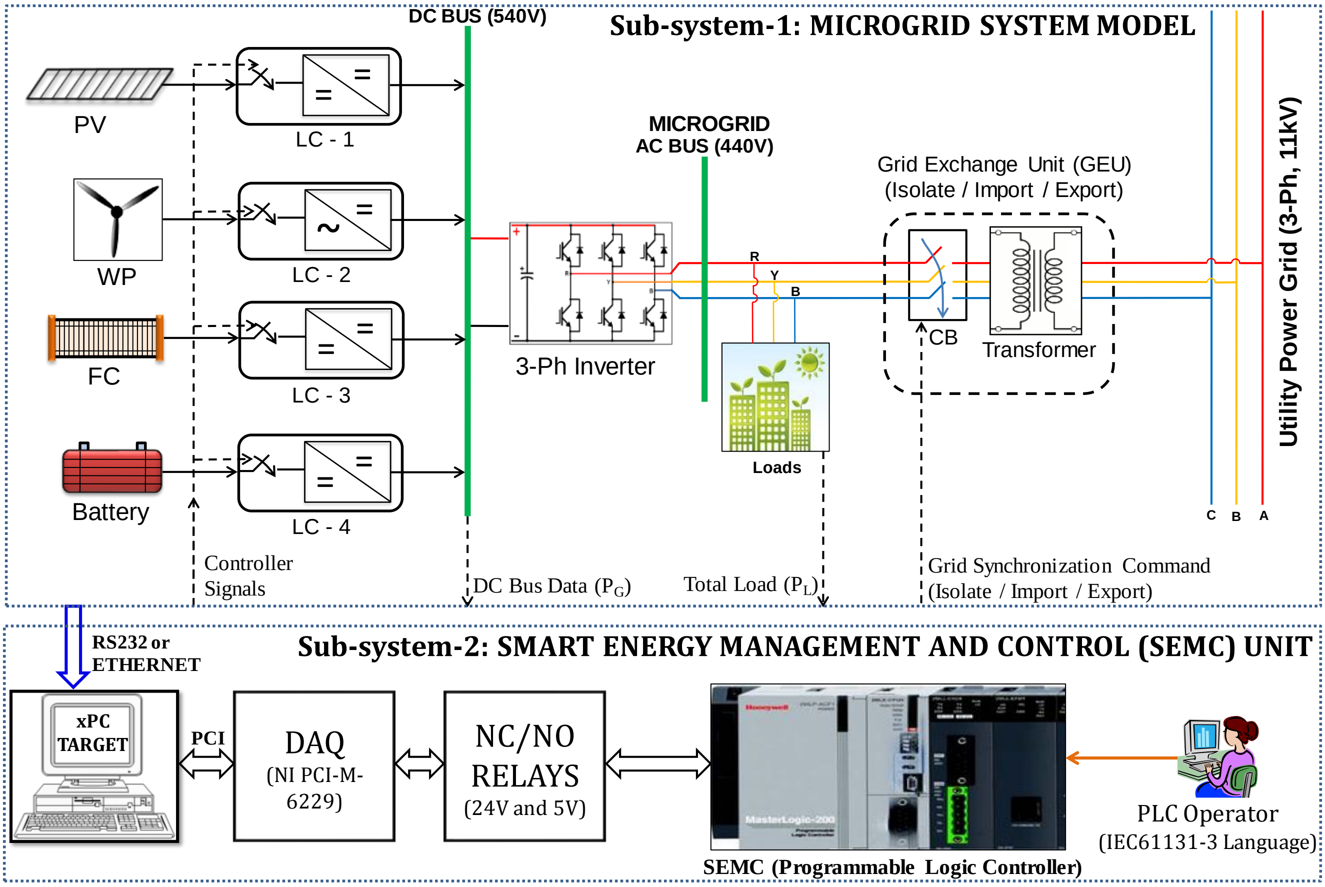


Fig. 1: Proposed hardware in the loop (HIL) test setup for real-time energy management and control of microgrids.

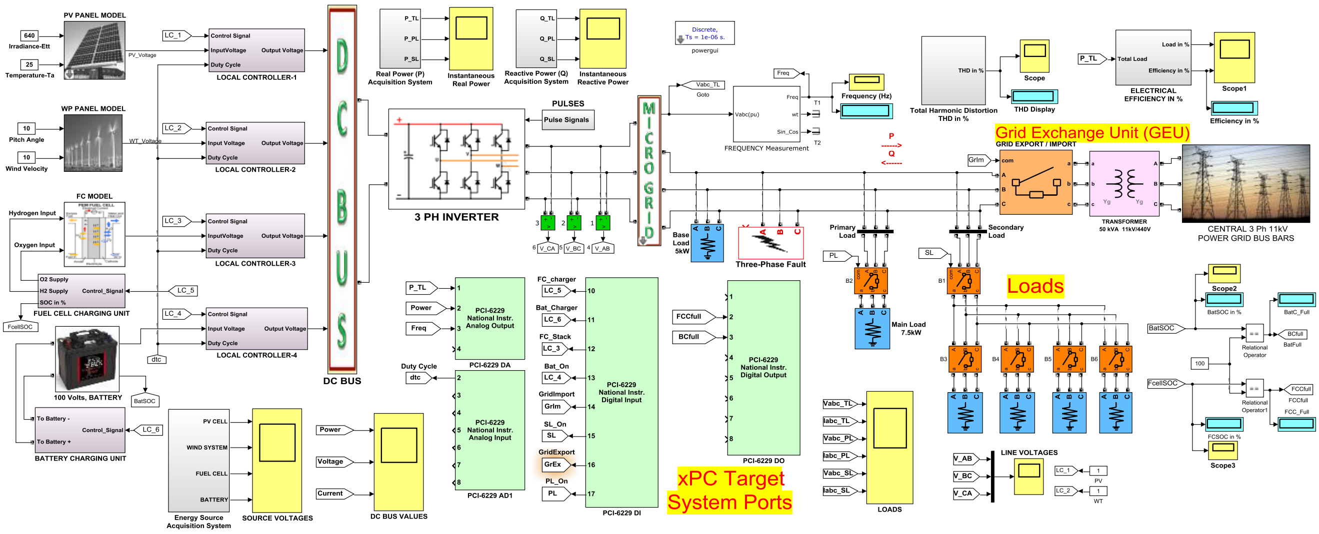


Fig. 2: Microgrid architecture modeled in MATLAB/Simulink for HIL testing.

The microgrid schematic shown in Fig.1 is modeled as shown in Fig.2 for its real-time operation along with SEMC unit.

3.2. Local Controller (LC) Modeling

LC model shown in Fig.3 works as an agent, which supports multi-agent theory [16], [17], [33], [34]. It is basically a combination of a switch (toggle) and DC (or AC)-to-DC converter. The LC takes an input control signal from SEMC unit and control the corresponding energy source or load connectivity to microgrid. The LCs are modeled based on specifications given in Table 1.

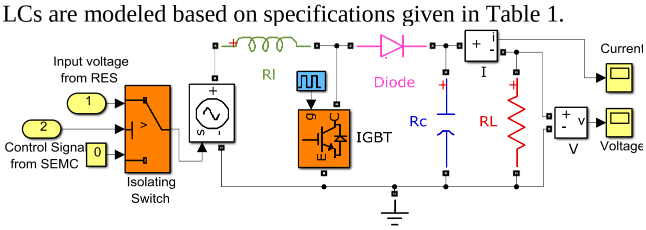


Fig. 3: Local controller (LC) model developed in MATLAB/Simulink.

- ON-state: IGBT switch is closed, which leads to flow of current (I_L) through the inductor during time "*t sec*". Correspondingly a voltage (V_i) appears across the inductor as per (1).
- Off-state: IGBT switch is open. Thus, I_L flows through load according to (2). The required DC output voltage will be produced by choosing proper voltage duty cycle (*D*) as given in (3).

$$V_i = L(\Delta I_L / \Delta t) \quad (1)$$

$$I_L = \int \left((V_i - V_o)/L \right) dt \quad (2)$$

$$D = 1 - (V_i / V_o) \quad (3)$$

Where; V_o = Desired output voltage, V_i = Input voltage

Table 1: Modeling Specifications for Boost Converter

S. No	Component / Parameter	Specification
1.	Capacitance (C)	45 µF
2.	Inductance (L)	255 µH
3.	Load resistance (R_L)	26 Ω
4.	Series resistance of Capacitor (R_c)	0.15 Ω
5.	Series resistance of inductor (R_l)	0.15 Ω
6.	Switching frequency (F_s)	51 kHz
7.	Required output voltage (V_{ref})	220 V

3.3. Modeling of The Power Inverter

IGBTs based three phase inverter is developed in MATLAB/ Simulink as per the design values shown in Table 2. The inverter control pulses are produced in a closed PID control loop as shown in Fig.3 through carrier wave (triangular) and modulating wave (sinusoidal) continuous comparison. The input to PID controller is difference signal of the reference voltage and the inverter output voltage (as feedback).

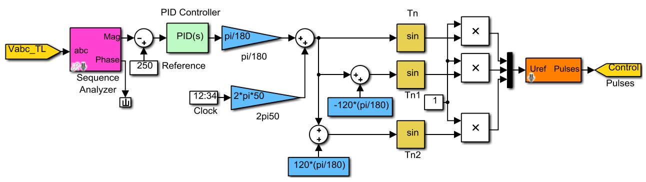


Fig. 4: Closed loop PID control loop to produce inverter firing pulses

Table 2: Three Phase Inverter Modeling Specifications

S. No	Parameter	Specification
1.	Type of power electronic switch	IGBT (+ Diode)
2.	Number of inverter arms	3
3.	Snubber capacitance (C_S)	∞ µF
4.	Snubber resistance (R_S)	$1e^5$ Ω
5.	Falling time (T_F)	$1e^{-6}$ Sec
6.	ON resistance (R_{ON})	$1e^{-3}$ Ω
7.	Total time (T_T)	$2e^{-6}$ Sec
8.	Carrier Frequency	1.08 kHz

4. SEMC Unit Modeling

Typical inputs and outputs used for SEMC implementation and the detailed proposed SEMC algorithm are given in Fig.5 and Fig.6 respectively.

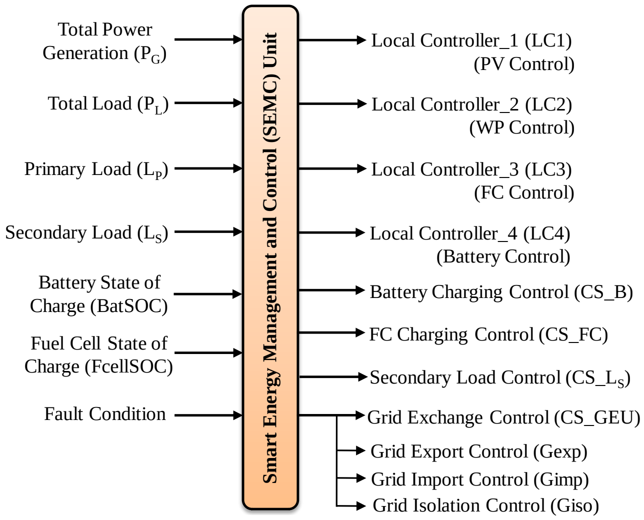
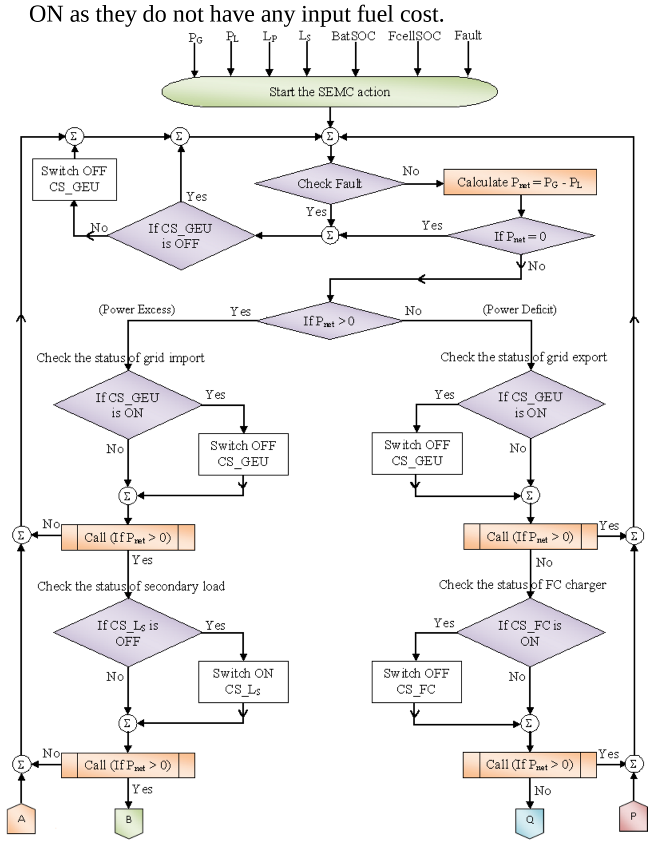


Fig. 5: Typical inputs and outputs to design SEMC strategy

4.1. SEMC Unit Operation

- SEMC principle basically works on three conditions viz;
  - ✓ $P_G = P_L$ (Sufficient Power condition)
  - ✓ $P_G > P_L$ (Excess Power condition)
  - ✓ $P_G < P_L$ (Deficit Power condition)
- Total power generated P_G (=$P_{DC\ BUS}$) is sum of outputs of all energy resources. Total demand P_L is the collective demand of all types of loads (L_P and L_S). WP and PV are always switched ON as they do not have any input fuel cost.



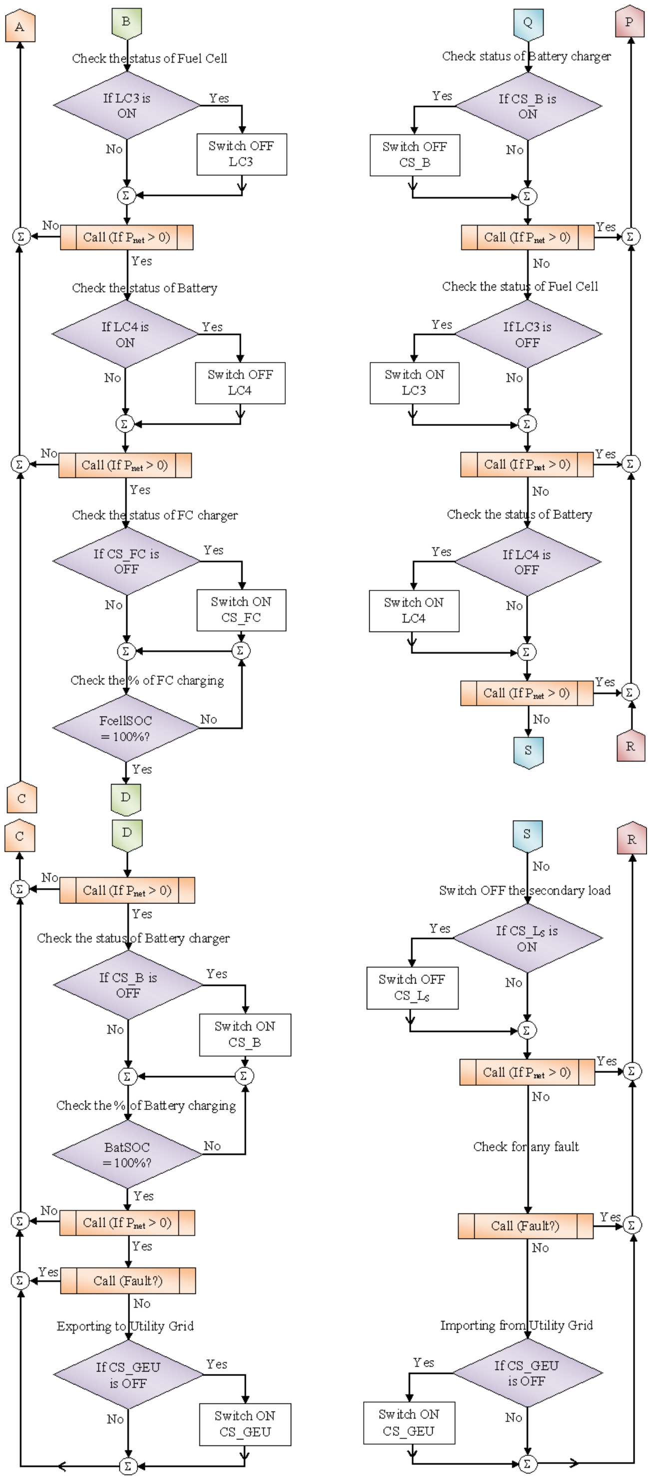


Fig. 6: Proposed algorithm for SEMC design

- P_G is equal to P_L indicates sufficient power. SEMC unit will not disturb the system and lets the system carry on as it is in the previous state until unless occurrence of any fault.
- P_G is more than P_L, represents excess power generation, which is used for hydrogen extraction in electrolyzer of FC or for battery charging. If the SEMC unit finds still excess power, it commands GEU to export excess power to utility grid.
- P_G is less than P_L, indicates deficit power, in this case FC unit is switched ON and charging of FC & battery are OFF.
- Further, the batteries are also operated as per the demand, and even further it is deficit, balance power is provided by utility.

This process of switching among the energy resources and load continues by depending upon generation and load, thus, leads to reliable and economic system operation by effective use of energy.

5. HIL Test Setup Development

The proposed HIL configuration is shown in Fig.7. This is developed over MATLAB/Simulink–xPC–DAQ–PLC units, where,

- MATLAB/Simulink is used for modeling of the microgrid.
- xPC target is used as an interface between the MATLAB/ Simulink model and the hardware controller through DAQ.
- PLC is used to realize the SEMC actions.

Table 3 gives resources used for the proposed setup development. Initially, xPC target kernel is developed by running xPC target executable file on target PC. It converts microgrid model in host PC to executable at target PC for real-time interfacing. One side of DAQ (NI-PCI 6229-MIO) is connected to target PC and other side is connected to PLC through relays as shown in Fig.7.

Table 3: Resources Required for Proposed HIL Setup

Name of the Resource	Specification Used
Industrial PCs	TCS-025-01786-002
MATLAB/Simulink with xPC target, RTW target tool box	Mathworks – R2009a Mathworks – xPC 4.3
MIO (Multi Input/output) for Data Acquisition (DAQ), Connector, Cable	NI PCI 6229 - M series, SCB-68A,SHC68-EPM
PLC (CPU - 230V AC, I/O - 24V DC)	Honeywell - ML 200R
Relay Boards	5V – NO/NC – 1 No 24V – NO/NC – 1 No
Power Supplies	230V AC-1No, 5V DC-1 No, 24V DC-1 No

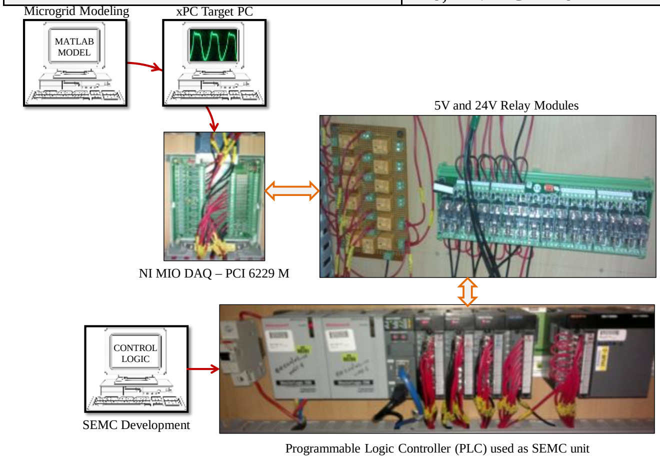


Fig. 7: Proposed HIL setup for real-time implementation of SEMC

6. Simulation Results

To test the proposed method, a case study with input data of a real-time location is assumed as given in Table 4. The simulation of microgrid in MATLAB/Simulink is carried out for 12sec with a set of 12 dissimilar data inputs. This denotes the microgrid profile (source and load) at different times of a day considered in each season. Each season is divided into 3 different times of a day, i.e., morning, afternoon, and night. For instance, if the first 3sec of the simulation denote the monsoon season, in that, 1st sec denotes morning, 2nd sec denotes afternoon, and 3rd sec denotes night. Also, it is assumed that the microgrid runs in grid-connected operation for first 8sec of the simulation.

At the 9th sec, a fault is created and is continued till 12th sec as shown in Fig. 8. Thus, the microgrid runs in island mode for the last 3sec. The corresponding simulation results are given by Fig.9-Fig.11. The real-time simulation through proposed HIL setup is conducted throughout a day and the corresponding results are given by Fig.12-Fig.14. The SEMC unit always checks the conditions of total load, generation, and fault and commands GEU to manage available RES and load at any time instant. The cumulative effect of total power exchange is shown in Table 5.

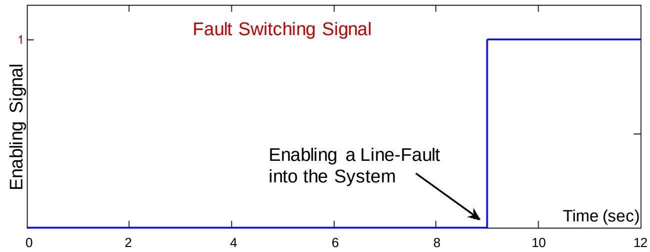


Fig. 8: Fault occurrence at 9th second of the simulation

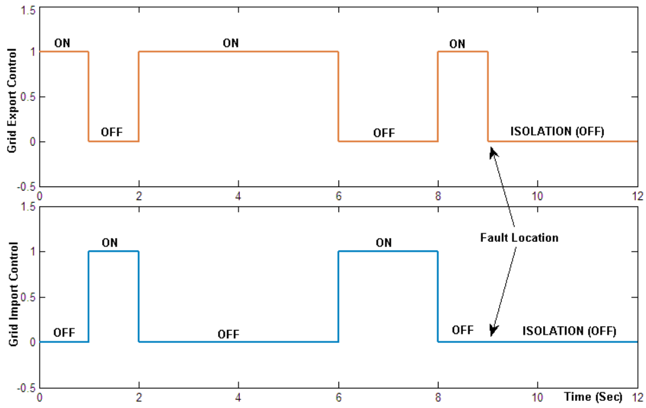


Fig. 9: SEMC unit control signals to grid exchange unit

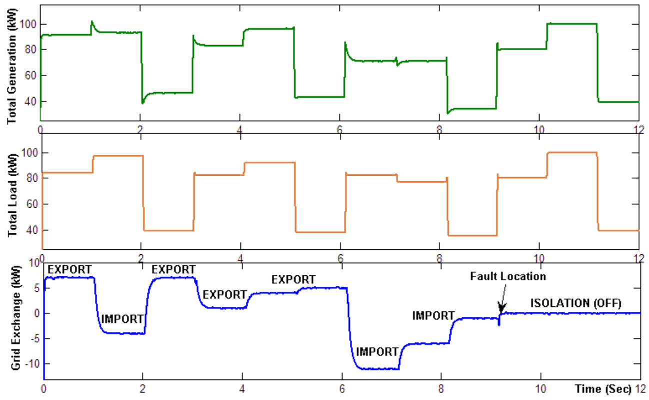


Fig. 10: Grid exchange based on SEMC commands

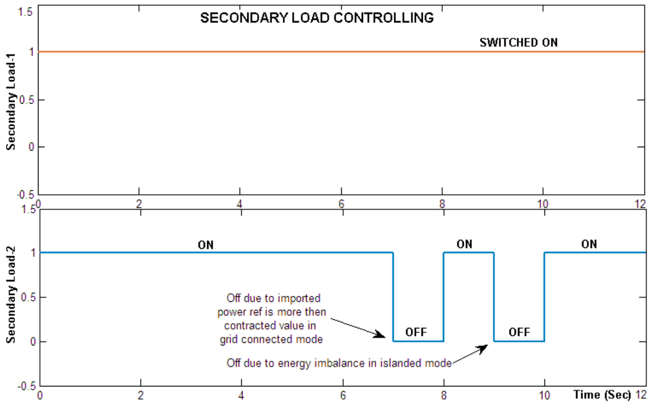


Fig. 11: Secondary load control based on SEMC commands

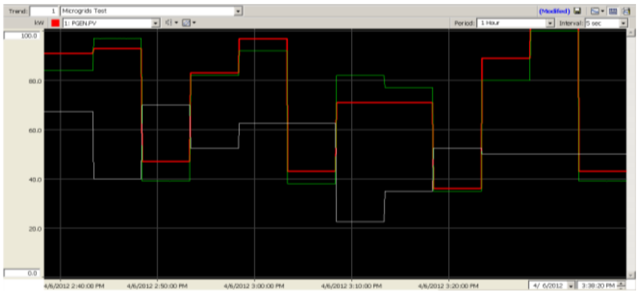


Fig. 12: Real time signals indicating P_G of various energy sources

Table 4: Input Pattern Given to Perform HIL Test

Day Considered with Season		Energy Source Input Profile: Temperature (°C)	Energy Source Input Profile: Irradiation (kWh/m²)	Energy Source Input Profile: Wind Velocity (m/s)	Different Load Profile: Primary Load (kW)	Different Load Profile: Secondary Load-1 (kW)	Different Load Profile: Secondary Load-2 (kW)
Day in Monsoon	Morning	29.50	4.45	4.72	52.50	20.50	11.50
	Afternoon	30.80	4.78	4.92	60.05	21.50	15.25
	Night	16.90	0.00	4.55	22.85	10.10	05.95
Day in Post Monsoon	Morning	27.90	5.02	4.28	51.05	20.50	11.50
	Afternoon	29.50	5.11	5.11	57.50	20.05	15.05
	Night	15.50	0.00	4.09	23.00	09.95	05.25
Day in Winter	Morning	25.50	5.55	3.69	50.90	20.00	11.25
	Afternoon	27.50	5.45	3.89	56.95	20.50	10.10
	Night	15.00	0.00	3.71	23.05	07.50	05.04
Day in Summer	Morning	33.85	6.42	4.28	56.98	22.95	14.95
	Afternoon	35.00	6.58	5.09	60.05	25.00	14.95
	Night	18.20	0.00	4.09	23.10	10.15	06.50

Table 5: SEMC Action Observations

Time Instant	Power Excess/Deficit	Fault	Grid Export	Grid Import
t = 0.5 sec	Excess	NO	ON	OFF
t = 1.6 sec	Deficit	NO	OFF	ON
t = 8.9 sec	Sufficient (P_G=P_L)	NO	OFF	OFF
t = 9.8 sec	Deficit	YES	OFF	OFF
t=10.7 sec	Excess	YES	OFF	OFF
t=11.5 sec	Sufficient (P_G=P_L)	YES	OFF	OFF

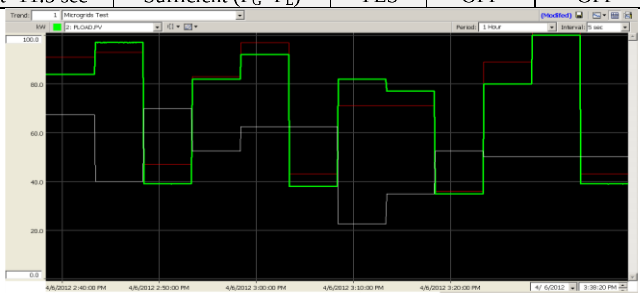


Fig. 13: Real time signals indicating various load variation

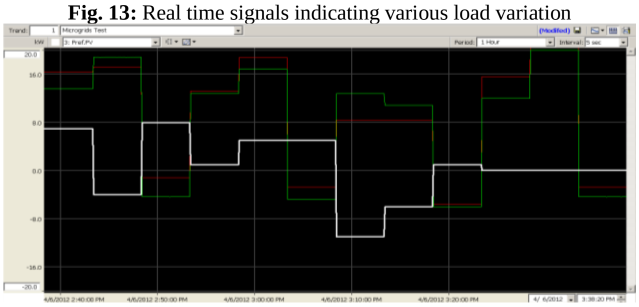


Fig. 14: Power exchange between microgrid and utility grid

7. Conclusion

The design and development of SEMC strategy through HIL setup for the microgrids at urban community environment was discussed in this paper. This rises the practicality of microgrids' design to cater the sustaining load demands and get free of utility grid outage issues. The key benefits of this strategy are as follows.

- ✓ The proposed system possesses great design fidelity and allows the operators/control personal to make a comprehensive and informed decisions on the overall facility management.
- ✓ The proposed SEMC can effectively manage the flow between power generation and load demand and leads to optimal utilization of available resources.
- ✓ The proposed system can effectually connect the utility power grid for power import/export during deficit/excess power cases.

Hence, the proposed system tolerates the ecological and load changes, thereby brings optimal use of available resources.

References

[1] Y. V. Pavan Kumar, Ravikumar Bhimasingu, "Review and retrofitted architectures to form reliable smart microgrid networks for urban buildings," *IET Networks Journal*, Vol. 4, No. 6, pp. 338-349, 2015.

[2] Caisheng Wang, M. Hashem Nehrir, "Power management of a stand-alone Wind/Photovoltaic/Fuel cell energy system," *IEEE Trans. Energy Conversion*, Vol. 23, No. 3, pp. 957-967, 2008.

[3] Erkan Dursun, Osman Kilic, "Comparative evaluation of different power management strategies of a stand-alone PV/Wind/PEMFC hybrid power system," *Elsevier International Journal of Electrical Power & Energy Systems*, Vol. 34, No. 1, pp.81-89, 2012.

[4] Y.V.P. Kumar, B. Ravikumar, "Integrating renewable energy sources to an urban building in India: challenges, opportunities, and techno-economic feasibility simulation," *Springer Technology and Economics of Smart Grids & Sus. Energy*, Vol. 1, No. 1, pp. 1-16, 2016.

[5] T. Senjyu, T. Nakaji, K. Uezato, T. Funabashi, "A hybrid power system using alternative energy facilities in isolated island," *IEEE Trans. Energy Conversion*, Vol. 20, No. 2, pp. 406-414, 2005.

[6] T.T. Chan, "Transient analysis of integrated solar/diesel hybrid power system," School of ITEE publication, Victoria University, 2011.

[7] Y.J. Reddy, Y.V.P. Kumar, K.P.Raju, A.Ramsesh, "Retrofitted hybrid power system design with renewable energy sources for buildings," *IEEE Trans. Smart Grid*, Vol. 3, No. 4, pp. 2174-2187, 2012.

[8] Yu Zhang, Nikolaos Gatsis, Georgios B. Giannakis, "Robust energy management for microgrids with high-penetration renewables," *IEEE Trans. Sustainable Energy*, Vol. 4, No. 4, pp. 944-953, 2013.

[9] Raghu Sankarayogi, "Software tools for real-time simulation and control," VDM Verlag Dr. Müller Publications, Germany, 2010.

[10] Y. J. Reddy, Y. V. P. Kumar, A. Ramsesh, S. Dash, K. P. Raiu, "Monitoring and power scheduling of a microgrid with distributed real time controllers in dynamically simulated environment," in *Proc*. IEEE 5th Power India Conference, 2012.

[11] A.V. Prokhorov, A.S. Gusev, Y.S. Borovikov, "Hardware-in-the-loop testbed based on hybrid real time simulator," in *Proc*. IEEE PES ISGT Europe Conference, 2013.

[12] F. Guo, L. Herrera, M. Alsolami, H.Li, P.Xu, X.Lu, A.Lang, J. Wang, Z. Long, "Design and development of a reconfigurable hybrid Microgrid testbed" in *Proc*. IEEE Energy Con. Congress & Exposition, pp. 1350-1356, 2013.

[13] M. Shoaib, L. Vanfretti, "Performance evaluation of protection functions for IEC 61850-9-2 process bus using real-time hardware-in-the-loop simulation approach" in *Proc*. IEEE 22nd Int. Conf. & Exhibition on Elec. Dist., 2013.

[14] D. Bazargan, S. Filizadeh, G. Bistyak, "Battery characterization for vehicular applications using hardware-in-loop real-time simulation," in *Proc*. IEEE 3rd Int. Conf. on Electric Power & Energy Conversion Systems, pp.1-6, 2013.

[15] O. Konig, C. Hametner, G. Prochart, S. Jakubek, "Battery emulation for power-HIL using local model networks and robust impedance control," *IEEE Trans. Ind. Elec.*, Vol. 61, No. 2, pp. 943- 955, 2014.

[16] M. Mao, P. Jin, N.D. Hatziargyriou, L. Chang, "Multiagent-based hybrid energy management system for microgrids," *IEEE Trans. Sustainable Energy*, Vol. 5, No. 3, pp. 938-946, 2014.

[17] Y. Zheng, Y. Song, D. J. Hill, Y. Zhang, "Multiagent system based

microgrid energy management via asynchronous consensus ADMM," *IEEE Trans. Energy Con.*, Vol.33, No.2, pp.886-888, 2018.
[18] R. P. Behnke, C. Benavides, F. Lanas, B. Severino, L. Reyes, J. Llanos, D. Saez, "A microgrid energy management system based on the rolling horizon strategy," *IEEE Trans. Smart Grid*, Vol. 4, No. 2, pp. 996-1006, 2013.
[19] Y. J. Reddy, Y. V. P. Kumar, A. Ramsesh, K. P. Raju, "Dynamic control algorithm for energy management in hybrid power systems with a novel design for power quality improvement," International Journal of Scientific Research, Vol. 2, No. 5, pp. 150-156, 2013.
[20] F. Valencia, J. Collado, D. Saez, L. G. Marin, "Robust energy management system for a microgrid based on a fuzzy prediction interval model," *IEEE Trans. Smart Grid*, Vol. 7, No. 3, pp. 1486-1494, 2016.
[21] J. Shen, C. Jiang, Y. Liu, Xu Wang, "A microgrid energy management system and risk management under an electricity market environment," *IEEE Access Journal*, Vol. 4, pp. 2349-2356, 2016.
[22] N.Rezaei, A.Ahmadi, A.H.Khazali, J.M.Guerrero, "Energy and frequency hierarchical management system using information gap decision theory for islanded microgrids," *IEEE Trans. Ind. Elec.*, Vol.65, No.10,pp.7921-7932,2018.
[23] K. D. Brabandere, K. Vanthournout, J. Driesen, G. Deconinck, R. Belmans, "Control of microgrids," in *Proc*. IEEE PES GM, 2007.
[24] C. Cristea, J. P. Lopes, M. Eremia, L. Toma, "The control of isolated power systems with wind generation," in *Proc*. IEEE Lausanne Power Tech, pp. 567-572, 2007.
[25] O.Omari, E.Ortjohann, A.Mohd, D.Morton, "An online control strategy for dc coupled hybrid power systems" *Proc*. IEEE PESGM 2007.
[26] A. Mohd, E. Ortjohann, W. Sinsukthavorn, M. Lingemann, N. Hamsic, D. Morton, "Supervisory control and energy management of an inverter-based modular smart grid," in *Proc*. IEEE/PES Power Systems Conference and Exposition, pp. 1-6, 2009.
[27] C. Jin, P. Wang, J. Xiao, Yi Tang, F. H. Choo, "Implementation of hierarchical control in dc microgrids," *IEEE Trans. Industrial Electronics*, Vol. 61, No. 8, pp. 4032-4042, 2014.
[28] R. K. Pillai, "Smart grid vision and roadmap for India," Published by India Smart Grid Forum (ISGF), 2013. ISGF Document
[29] Y. J. Reddy, Y. V. P. Kumar, K. P. Raju, A. Ramsesh, "PLC based energy management and control design for an alternative energy power system with improved power quality," *Int. Journal of Engineering Research and Applications*, Vol. 3, No. 3, pp. 186-193, 2013.
[30] B. Delfino, F. Fornari, "Modeling and control of an integrated fuel cell-wind turbine system," in *Proc*. IEEE Bologna Power Tech Conf. Proc., Vol. 2, pp. 23-26, 2003.
[31] M. Arifujjaman, M. T. Iqbal, J. E. Ouaicoe, M. J. Khan, "Modeling and control of a small wind turbine," in *Proc*. IEEE Canadian Conference on Electrical and Computer Engineering, pp. 778-781, 2005.
[32] J.Singh, R.Mittal, D.K. Jain, "Improved performance of diesel driven permanent magnet synchronous generator using battery energy storage system," in *Proc*. IEEE Electrical Power & Energy Conf., 2009.
[33] G. Li, Y. Chen, T. Li, "The realization of control subsystem in the energy management of wind/solar hybrid power system," in *Proc*. 3rd Int. Conf. on Power Electronics Systems and Applications, 2009.
[34] C. Rehtanz, "Autonomous systems and intelligent agents in power system control and operation," Springer Book, 2010.