Journal of Electrical Engineering and Science, Vol. 2(2) 2016, pp. 1-11

RESEARCH ARTICLE

A Novel Energy Management System using Renewable Distribution Generation Units

*A.O Deepa[1], R Lal Raja Singh[2], R Leena Rose[3]
[1]Marthandam College of Engineering and Technology, Kuttakuzhi, Veeyannoor, Kanyakumari, Tamil Nadu, India.
[2]Kalaignar Karunanidhi Institute of Technology, Kannampalayam, Coimbatore, Tamil Nadu, India.
[3]Sasurie Academy of Engineering, Kariyampalayam, Coimbatore, Tamil Nadu, India.

Received- 17 March 2016, Revised- 27 May 2016, Accepted- 9 July 2016, Published- 23 August 2016

ABSTRACT

Energy management techniques such as adaptive proportional resonance and advanced droop controllers are incorporated in micro grid systems in addition to distribution generation units and grids to regulate load voltage and to distribute power efficiently in the distributed generation units. A predictive control algorithm is implemented to enable computational time efficiency for complex operations by solving steady state and transient control problems.

Keywords: Energy management, Adaptive proportional resonance, Droop controller, Distributed generation, Predictive control algorithm.

1. INTRODUCTION

Energy management strategies are ought to be designed in a way that they balance between the arising needs such as higher performance and the negative factors like power loss. The project is done in a similar way by considering the devices used, requirements and the actual performance. Micro grid is the prime component used in the experiment. It is the power grid that works independently with the primary electrical grid. This can even operate in connection to the main grid via common coupling to function under unit power control or feeder flow control mode. It includes distribution generation units connected to the distribution grid which employs an adaptive proportional resonance and a droop control system to regulate load voltage and to distribute average power respectively. The working of the distribution generation units is coordinated by means of energy management algorithm. Micro grid consists of photovoltaic array and a proton exchange membrane fuel cell where a lithium ion battery is also included for power management during both the grid connected and islanded processing.

A number of distributed energy systems are integrated to the energy systems in the power grid by adapting micro grid. Here, initial cost is reduced and the efficiency of micro grid is enhanced by intelligent power electronic interfaces and a smart switch using resynchronization principle so that the system realization gets accelerated in passing the heat output or providing high quality power to certain loads in the network. At any unusual circumstances such as noisy or faulty criteria, the distribution system automatically isolates from the load in-order to protect the grid unit. The smaller the size of the generation units, the overall efficiency is higher in terms of heat loads and waste heat energy transfer.

The availability of distributed generators aids in integration of renewable energy resources to the distribution networks and hence it is an advantage to power system operators and consumers. Since these are available in smaller size, they are operated at close proximity to consumers that are installed and maintained at a considerably lower cost function. Integrated distribution generation with the power converters provide adaptable auxiliary functions such as power quality

*Corresponding author. Tel.: +919443371311
Email address: leena_eee2002@yahoo.co.in (A.O.Deepa)
Double blind peer review under responsibility of DJ Publications
http://dx.doi.org/10.18831/djeee.org/2016021001

improvement, power grid stability and reliability to the power grids. Micro grid operation requires a robust control technology to perform load sharing among various distribution generation systems. Some of the applications of renewable micro sources include wind turbines, heat and power integrators and internal combustion inverters. The decentralization strategy makes the distribution generation more reliable and further reliability is attained by allowing the distributed generation to function autonomously in transient environments. Certain fields where the energy resource optimization is required are,

- Peak-shaving
- Power and waste heat management
- Fuel selection
- Centralised load control
- Emission monitoring
- Compliance with interface modes
- Building system control

Multiple small sized generators are preferred due to the following reasons.

- To avoid high standby charges
- To enable reduction in failure of the system
- To provide efficiency and
- To access other units in the network in case of faults.

The two components of the micro grid are static switch and micro source. The purpose of the static switch is to island (continuation of power supply to a device or a system by a distributed generator in the absence of power grid) the micro grid from any unusual changes in the network. Once the islanding event gets over, micro grid can be reconnected automatically after the completion of tripping event by using frequency difference achieved in between the islanded micro grid and the utility grid. The micro source in the grid balances the power of the islanded micro grid via power versus frequency droop controller. [1, 2] Hybrid electric vehicles power control using fuzzy logic relating to energy management was employed to overcome the demerits of the traditional control methods. Though one of the drawbacks of fuel efficiency was successfully enhanced, this could be performed under complex driving force and not for ordinary conditions. Hence this result in a drawback that, for the design of complex structure, the proposed method seems to be complicated by the enrolment of dynamic programming model. The rule based control model used in the project leads to high operational efficiency and robustness under systematic control design, high cost and longer time period. The study lags in real time analysis which could be obtained on the basis of real time driving. [3] A stand-alone hybrid model to manage power was adapted to regulate power flow between the primary and secondary units. It is comprised of photovoltaic panel, wind mill, and diesel engine as energy sources and battery bank as storage unit. Since the power sources are many, any one of the units may be considered for operation at a time depending upon the environmental changes. Despite using several approaches in dealing with their feasibility and reliability, these could not show any evidences of fulfilling the basic requirements such as cost and time effectiveness. [4, 5, 6] Power management in microprocessors was inscribed where it supports almost all electronic equipment. Dynamic Voltage and Frequency Scaling (DVFS) approach was implemented to survey power management models by defining reactive and predictive power control methods. In reactive modes, it acts as per workload changes and hence there develops a chance of lagging that persist between workload phase and power adaption mechanism so that it might result in performance degradation. These limitations are solved by predictive control mode since it predicts the changes before they arise and perform accordingly thereby optimising the performance outcomes. In certain occasion, if all the workloads could not be predicted, reactive methods are also engaged with that of predictive ones in solving energy saving and performance optimization. Some of the literal shortcomings of DVFS include less scalability, state transition delay in turn diminishing results. [7, 8] To maintain Quality of Service (QoS), DVFS based DEWTS (Energy efficient Workflow Task Scheduling Algorithm) was proposed as an improved version. The fact is that they could be actively used only for DVFS enabled devices and so the procedures make a long way to go. The approach could have been made even better if it would meet reliability in communication overhead, but the proposed method could be encouraged where heterogeneous circuits are involved. Heterogeneous modes are usually complex and in this case if DEWTS can make them work, promising results could be anticipated in this arena. [9] A comparison based on optimal Single Point Start-Stop and Operation Line power Track (SPSS vs. OLT) energy management methods was done and proved that the OLT power control method could be opted for better energy economy. The study also reveals that the OLT method is comparatively better but not obviously enough for fuel economy due to the cost issues of auxiliary power unit control. [10] To manage energy and to monitor and evaluate the control system the article implemented hardware in loop simulation with controller area network and rule based schemes. The simulation used in the process verified the effectiveness of the control mechanism by optimising the system factors in-order to enhance success rate. It provides good real time performance though it is a tedious approach. [11] introduced the implementation of frequency adaptive resonant controller for grid connected operation. The article aids in harmonic reduction but maintaining stability against frequency drifts should have been further stressed on. [12] Droop control over micro grids were analysed using wind generator. The whole set-up was formulated in a certain way with conditions and assumptions which makes the process still more complicated; else, the overall simulations are comparatively better. [13, 14, 15] In this context, a cooperative optimization concept was manifested under model predictive control mechanism. Along with other significances such as solving of optimization problems, it is proved to be efficient in minimization of total electricity cost of the operation system. From these works, it is concluded that predictive control would be a better option among energy management techniques.

In the proposed article, power quality has been improved by harmonic compensation via demand side management for non-linear loads and hence this scheme of grid system has entered over renewable generation of sources like wind and solar power models to supplement energy from the distribution grid. Most of the existing techniques in relation with renewable mode could not meet the most desirable effects in terms of reliability and stability of the distribution matrix. So, there is an absolute need for the requirement of additional energy storage equipment to compensate the present drawbacks. If one could manage its expensiveness, cooperating with its peak demands and load variation are not that easy to deal with. Here, the suggested mechanisms are recommended for handling cost factors as well as for other criteria mentioned above.

2. METHODOLOGY

2.1. Terms and factors

- Micro grid, as the term indicates is a large sector that incorporates a huge number of load clusters and micro sources as a single controllable unit to power the intended area.
- Micro sources are smaller units and of low cost usually situated at customer sites. It functions with low voltage providing high reliability.
- The use photovoltaic cells in the experiments assists in renewable energy and also adopts well to distributed urban energy sources since they are weightless (portable), noise free, durable and requires little maintenance.
- Inverter consists of power tracking unit, capacitor for energy storage and converter circuit for voltage enhancement.

The responsibility of the distribution system is to power the electronic devices at the customer spot as per the defined limit which can be related with respect to the design and expense range. Choosing the right distribution transformers, regulators and feeders are inevitable that these systems make the operation successful. Even location of each unit must be taken care of since negative impacts arise due to the misplacement of distributed generation unit (like placing DG unit behind the load tap-changer transformer).

Using of rotating machines, induction and synchronous generators might increase the chance of network failure and so these constraints must be checked by enabling impedance between the generator and the transformer network without compromising power loss and variations. In the same manner, transient voltage changes and harmonic distortions must be restricted, i.e. such slight variations are accepted when load fluctuates or during connection and disconnection of the generator.

2.2. System architecture and modelling

Micro grid offers uninterrupted monitoring and control by using simple units like relays and switches. Data and control information are its management resources that are handled by the controller. Micro grid consisting of distributed generation units with photovoltaic array is developed and the two main components in it are proton exchange membrane fuel cell for power compensation and lithium ion storage battery for power generation during energy crisis, maintaining the stability of the entire network and for peak shaving (reduction of power consumption in-order to save it). Other inventory modes make use of adaptive proportional resonance and droop control along with advanced predictive control algorithm. System performance is enhanced by defining several functionalities including energy usage analysis, demand and peak power usage management where power trade-off among micro grid stack-holders is also attained. Since the topology required is narrow, the overall processing is simple enabling portability and can be modified as per the requirement. The basic diagram depicting the above method is shown in figure 1.

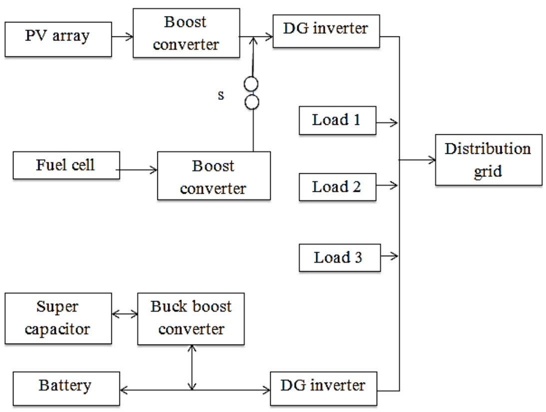

Figure 1.Block diagram of a micro grid

Micro grid used in the design structure is capable of working under both grid connected or islanded means. Distributed generated unit in the system consists of Photo Voltaic (PV) array as the main generation device and Proton Exchange Membrane (PEM) fuel cell to back-up the improper power supply of the PV array. They are of 40 kW and 15 kW accordingly in parallel to the inverter via two boost converters which regulates the DC link voltage. The operation of the photo voltaic cell depends upon the intensity of sunlight by enabling the maximum power point tracking process resulting in delivering of maximum DC power. If the resultant voltage of the PV array goes below the default value, it gets disconnected from the DG system. A storage battery (30 Ah Li ion) is fed to the DG inverter via bidirectional converter for charging mechanism and for power balancing in connected and islanded mode respectively. This is how the detailed circuit diagram of the micro grid operation looks like as shown in figure A1. The operation of battery in connected and islanded modes is explained by the help of two respective flow diagrams as shown in figure 2 and figure A2.

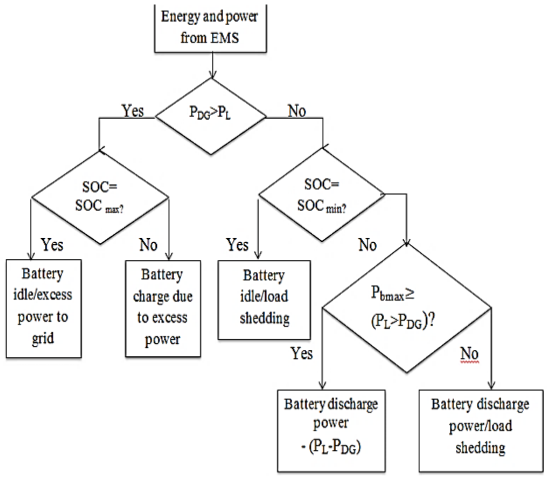

Figure 2.Battery operation in islanded mode

In the circuit, P_b denotes the real power supplying the load. The State of Charge (SOC) is determined by estimation procedures, where it is the deciding factor for the battery to be in active or idle state. The factors of power management including power flow, load forecasting and economic dispatch are controlled by the energy management system through centralised server where the data measurements from transformer, smart meters and circuit breakers are fed to the server via ethernet. When grid connected, the distribution and the micro grids are connected to each other by the circuit breaker at the junction of common coupling. Normally, the primary distributed generated unit reduces the workload of the distribution grid, but due to the emerging of additional devices in the network, harmonic deviation arises which lead to load current distortion. At this juncture, the distributed unit aids in reduction of harmonics and stops them from penetrating to other connected circuits.

Power variation tends to occur depending upon the loads or as per load demands. In case of generated power exceeding the load demand, the unused power is applied for battery charging or stored up. On the contrary, if the load demand is higher, then the battery is operated to obtain energy management values with respect to SOC and Time of Use (TOU). The off-peak and peak periods as in the flow chart are defined as:

- Off-peak period: If the grid power generation is low and the state of charge of the battery is lower than its maximum limit, then the battery gets charged by the grid, where the loads are powered from the primary DG unit and the grid.
- Peak period: When the grid power generation is high and SOC of the battery is beyond the maximum, battery powers the grid to attain peak shaving.

Any fault in the upstream network enables the circuit operator to fix the problem by isolating the micro grid from the distribution grid. At such circumstances, the primary DG unit and the battery supply power and regulate the load systems, if not, load shedding is applied to bring back the shifted frequency and to stabilise the micro grid.

2.3. Controller design and analysis

The design process can be categorised into Model Predictive Control design (MPC), Adaptive Proportional Resonant (APR) and droop control.

- MPC design helps in fetching periodic signals so that the dual mode functioning of the micro grid could be predicted.
- APR is the transfer function which resembles a closed loop.
- Droop controller is used to develop voltage and frequency reference by which an error signal is obtained by comparing the reference reading to that of actual values and thus the inverter can be brought to the desired operating point whenever it takes a wrong route.

The algorithm that is formulated for the design of novel predictive controller is modulated for the sake of fast sampling systems to detect the periodic signals so that the dual mode processing of the micro grid could be done. It disintegrates predictive control optimization to steady state and transient sub problem that is solved simultaneously in a receding horizon manner. Computational complexity is reduced by dynamic policy technique employed by the steady state stage. MPC design of DG inverter is shown in figure 3. One of the major merits of using predictive control technique is that it predicts the future requirements and based on which the control inputs are provided.

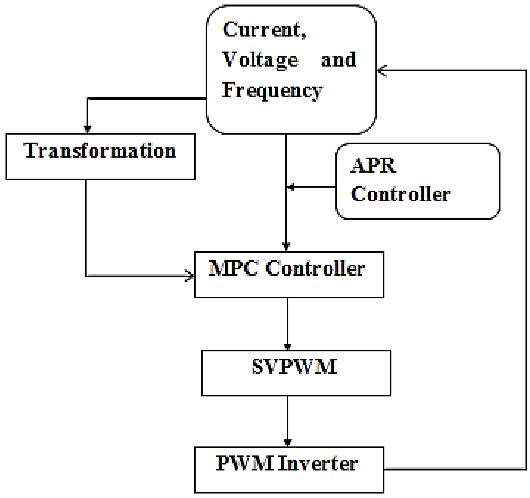

Figure 3.Model predictive controller

Figure 3 represents the basic concept of a model predictive controller where the transformed input is fed to the controller followed by Space Vector Pulse Width Modulation (SVPWM). The inverted signal is referred to the input control. Switching pulses are generated by SVPW modulator that makes the switching frequency fixed which further lowers the power ripple and helps in enhancing dynamic response. This model predictive control is a form of closed loop optimisation control which is able to handle time varying systems.

In the droop controller, the equations are implemented by inverter control which acts like a voltage source in addition to virtual resistive-inductive output impedance. The controller is designed as per Kalman state observer and control law of a linear quadratic Gaussian framework. The error report obtained from the comparison of voltage and frequency reference and the actual values are incorporated in the state observer and control law to get the inverter at the correct position.

3. RESULT AND DISCUSSION

The experiments are simulated using MATLAB software and the following results are obtained. The simulation models of the overall architecture and the micro grid of 22kV are given in figure A3 and A4 respectively. In figure A4, a 3-phase transformer and the circuit breaker connect the generating unit and the load on either side where the 3-phase transformer is of 0.4/22kV. The waveforms of grid voltage, current, linear and non-linear load are shown in figure A5, A6 and A7 correspondingly. Based on the analysis, it is concluded that the real and reactive power of the linear and non-linear loads are improved as depicted by the following diagrams. More or less for all the existing systems, the outputs of linear and non-linear loads were produced as shown in figure 4 and 5 and the waveforms shown in figure 6 and 7 resulted for the present structure.

In case of existing methods, for both the linear and non-linear loads, the real and reactive power values are -5.8kW and -4.8kvar and for the proposed one, the real and reactive power for linear and non-linear loads vary. All the given graphs are plotted against power with time in the x-axis. The blue and green curves in the MATLAB output as in the following diagram relates to the real and reactive power respectively. Though the results of linear waveforms are quite similar for both the existing and developed systems, a vast difference could be noticed in their corresponding non-linear waveforms. Thus it is clear that real and reactive power for non-linear load has been raised a lot and this does not mean that the power values are reduced for linear loads. A slight variation or enhancement is clearly visible in their results too.

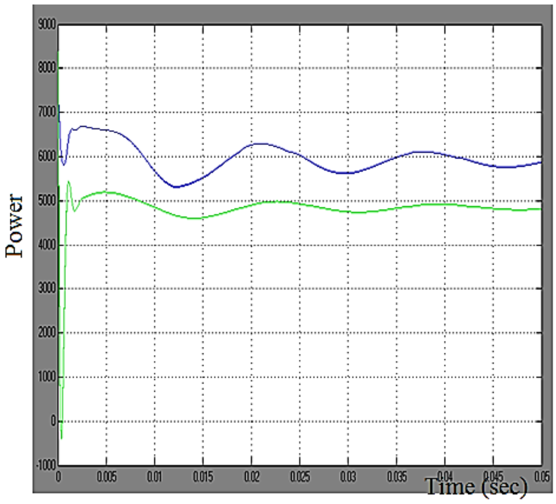

Figure 4.Linear waveform of the existing systems

For linear load, the real power is given as -6kW and the reactive power is -4.5kvar and its respective waveform is plotted as shown below, where the unit of the reactive power is denoted by volt-ampere reactive (var).

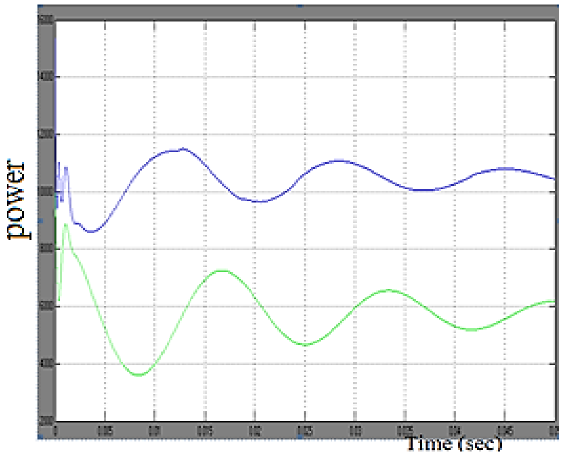

Figure 5.Non-linear waveform of the existing systems

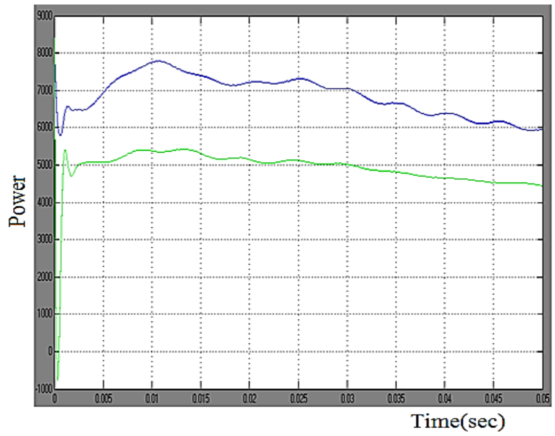

Figure 6.Linear waveform for the proposed system

Real and reactive power values are of -11kW and-8.4kvar and the related waveform is shown below.

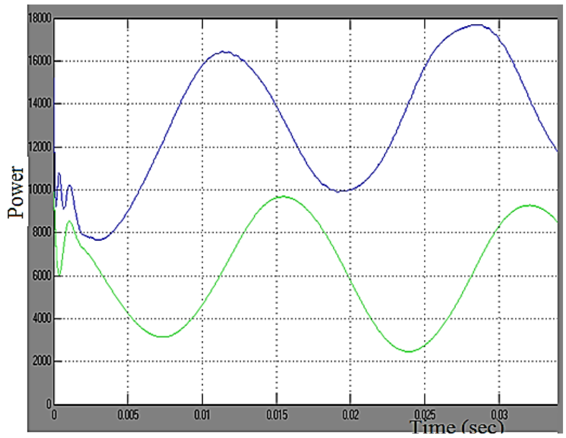

Figure 7.Non-linear waveform for the proposed system

The waveforms depicts that the load harmonic currents are compensated as it is performed along with traditional filtering methods. The advantages are

- No additional devices are needed.
- Real and reactive power enhancement.
- Compensation of harmonic voltage levels.
- Effective energy management.

4. CONCLUSION

Right from the beginning, present era researches have been focussed on demanding a smart grid system, but fails in achieving the best in one form or the other though several steps have been taken throughout. The proposed system is reliable and suits well for space and terrestrial applications. The concepts are investigated by keeping in view the present trend alterations that are common in electrical components. Any modifications are acceptable in the emerging innovations and the proposed simulations are devised in such a way to face it. There is no doubt that this method simplifies the existing methods by utilising distributed generated converters without the need of any additional equipment and thus improves the performance of energy management by the significant role of model predictive control design. Moreover, the outputs are validated under various operation modes which enhance the reliability and stability of the micro grid used. Further implementations are suggested in evaluation of compatible measurements to get better outcome in terms of time, energy and performance outlook.

REFERENCES

[1] Zhen Wei, Z.Xu and Dunant Halim, Study of HEV Power Management Control Strategy based on Driving Pattern Recognition, Energy Procedia, Vol. 88, 2016, pp. 847-853, http://dx.doi.org/10.1016/j.egypro.2016.06.062.

[2] Scott J.Moura, Jeffrey L.Stein and Hosam K.Fathy, Battery-Health Conscious Power Management in Plug-In Hybrid Electric Vehicles via Electrochemical Modeling and Stochastic Control, IEEE Transactions on Control Systems Technology, Vol. 21, No. 3, 2013, pp. 679-694, http://dx.doi.org/10.1109/TCST.2012.2189773.

[3] Menad Dahmane, Jerome Bosche and Ahmed El-Hajjaji, Power Management Strategy based on Weather Prediction for Hybrid Stand-alone System, Energy Procedia, Vol. 83, 2015, pp. 330-340, http://dx.doi.org/10.1016/j.egypro.2015.12.187.

[4] Khaled M.Attia, Mostafa A.El-Hosseini and Hesham A.Ali, Dynamic Power Management Techniques in Multi-Core Architectures: A Survey Study, Ain Shams Engineering Journal, 2015, http://dx.doi.org/10.1016/j.asej.2015.08.010.

[5] Fabio Diniz Rossi, Mauro Storch, Israel de Oliveira and Cear A.F.De Rose, Modeling Power Consumption for DVFS Policies, IEEE International Symposium on Circuits and Systems, Lisbon, 2015.

[6] Ruay-Shiung Chang, Chia-Ming Wu and Hsin-Yu Chan, A Green Energy-Efficient Scheduling Algorithm using the DVFS Technique for Cloud Datacenters, Future Generation Computer Systems, Vol. 37, 2014, pp. 141-147, http://dx.doi.org/10.1016/j.future.2013.06.009.

[7] Kenli Li, Samee U.Khan, Zhuo Tang, Ling Qi, Z.Cheng and Keqin Li, An Energy Efficient Task Scheduling Algorithm in DVFS-enabled Cloud Environment, Journal of Grid Computing, Vol. 14, No. 1, 2016, pp. 55-74, http://dx.doi.org/10.1007/s10723-015-9334-y.

[8] Juan J.Durillo, Vlad Nae and Radu Prodan, Multi-Objective Energy-Efficient Workflow Scheduling using List-Based Heuristics, Future Generation Computer Systems, Vol. 36, 2014, pp. 221-236, http://dx.doi.org/10.1016/j.future.2013.07.005.

[9] Wei Liu, Hongwen He and Zexing Wang, A Comparison Study of Energy Management for a Plug-in Serial Hybrid Electric Vehicle, Energy Procedia, Vol. 88, 2016, pp. 854-859, http://dx.doi.org/10.1016/j.egypro.2016.06.064.

[10] Lu Yi, Hongwen He and Jiankun Peng, Hardware-In-Loop Simulation for the Energy Management System Development of A Plug-In Hybrid Electric Bus, Energy Procedia, Vol.

88, 2016, 950-956, http://dx.doi.org/10.1016/j.egypro.2016.06.118.

[11] Ana R.Monter, E.J.Bueno, Aurelio Garcia-Cerrada, F.J.Rodriguez and F.M.Sanchez, Detailed Analysis of the Implementation of Frequency-Adaptive Resonant and Repetitive Current Controllers for Grid-Connected Converters, Electric Power Systems Research, Vol. 116, 2014, pp. 231-242, http://dx.doi.org/10.1016/j.epsr.2014.06.011.

[12] X.Zhao and F.Hong, Impacts of P-f & Q-V Droop Control on MicroGrids Transient Stability, Physics Procedia, Vol. 24, 2012, 276-282, http://dx.doi.org/10.1016/j.phpro.2012.02.041.

[13] A.Staino, H.Nagpal and Biswajit Basu, Cooperative Optimization of Building Energy Systems in an Economic Model Predictive Control Framework, Energy and Buildings, Vol. 128, 2016, pp. 713-722, http://dx.doi.org/10.1016/j.enbuild.2016.07.009.

[14] C.Wu, Growth of SrGaGe Nanowires by Thermal Annealing, Journal of Electrical Engineering and Science, Vol. 2, No. 1, 2016, pp. 1-14, http://dx.doi.org/10.18831/djeee.org/2016011001

[15] T.Rama Rajeswari, C Subramanian and R.Manivannan, Design of Full Bridge Buck Converter with a Fly Back Snubber for High Power Applications, Journal of Electrical Engineering and Science, Vol. 1, No. 2, 2015, pp. 1-14, http://dx.doi.org/10.18831/djeee.org/2015021001

APPENDIX

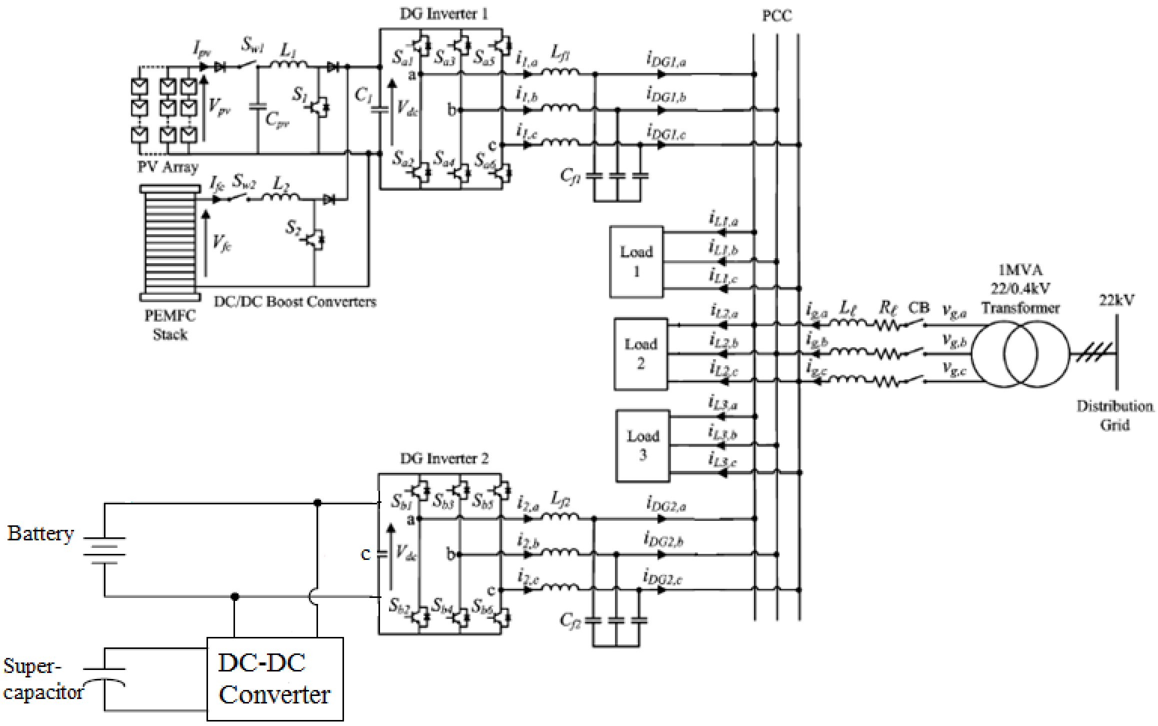

Figure A1.Circuit diagram of micro grid operation

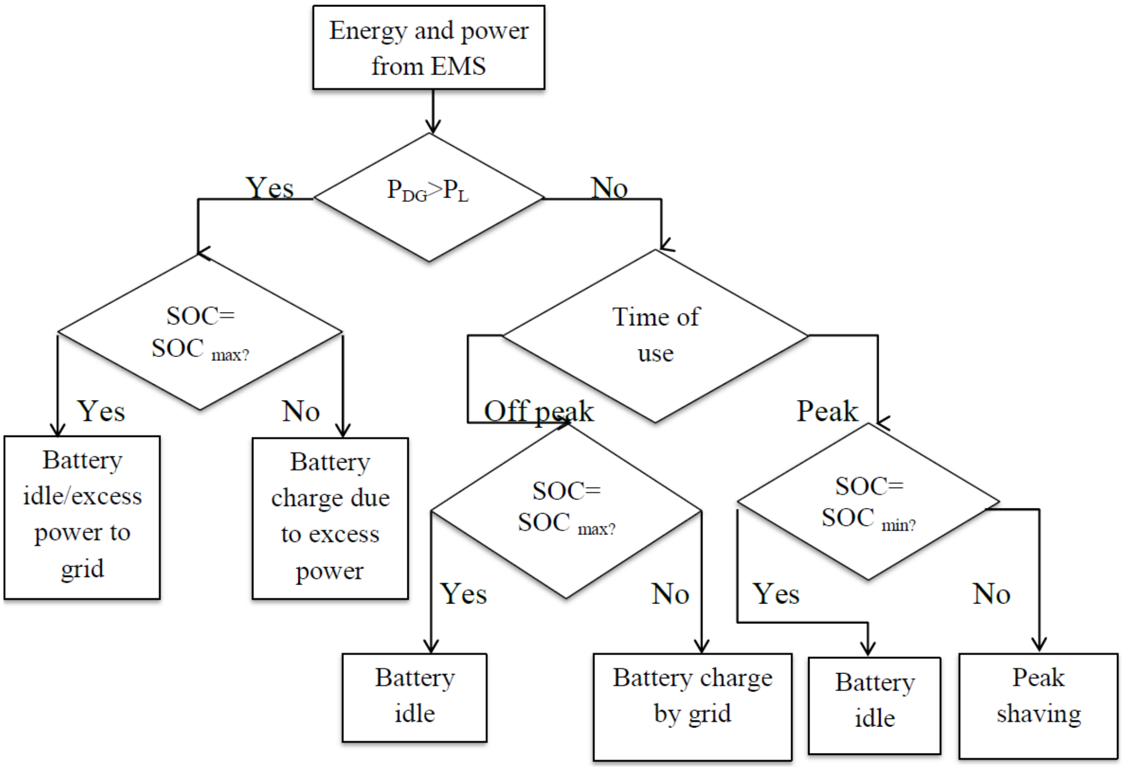

Figure A2.Battery operation in grid connected mode

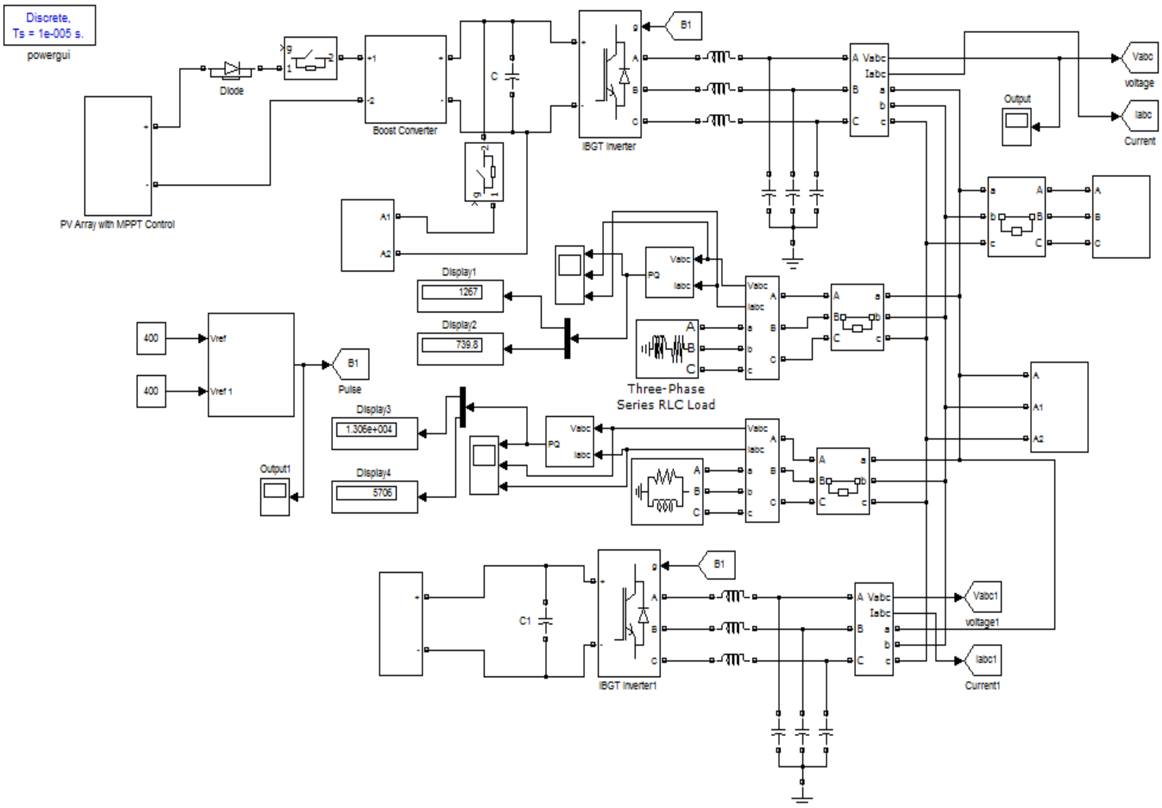

Figure A3.Simulation model of the developed system

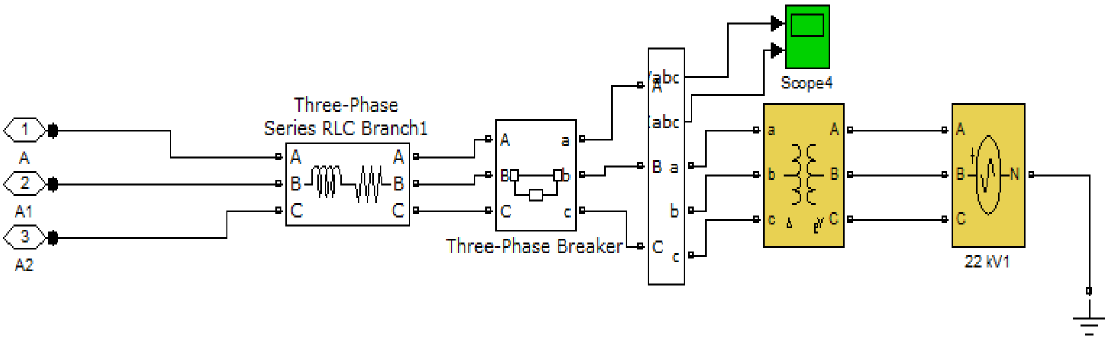

Figure A4.Simulation model of micro grid

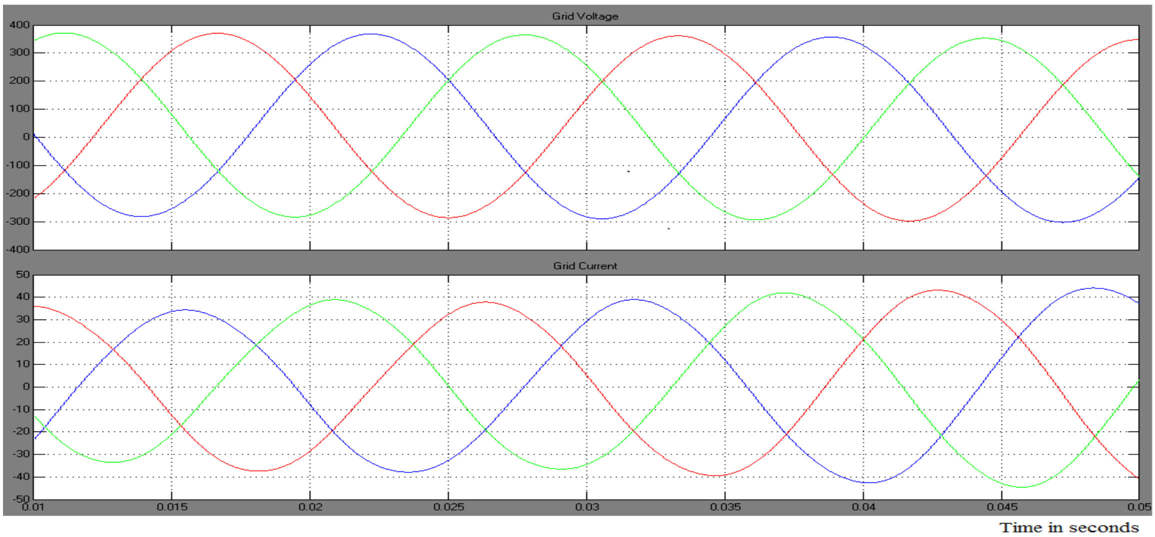

Figure A5.Grid voltage and current waveforms

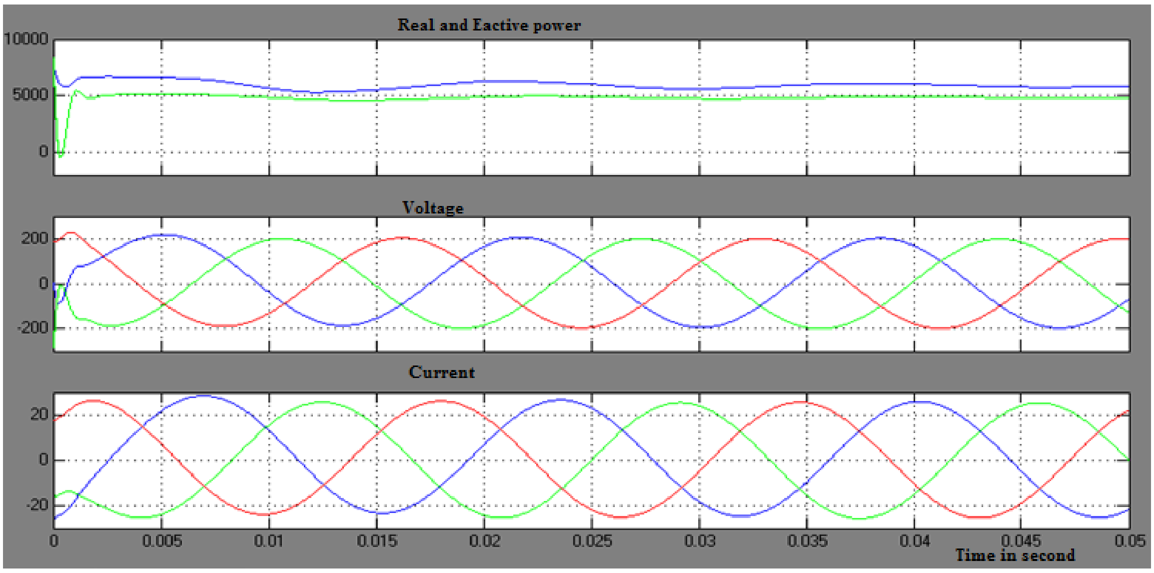

Figure A6.Waveforms of linear load

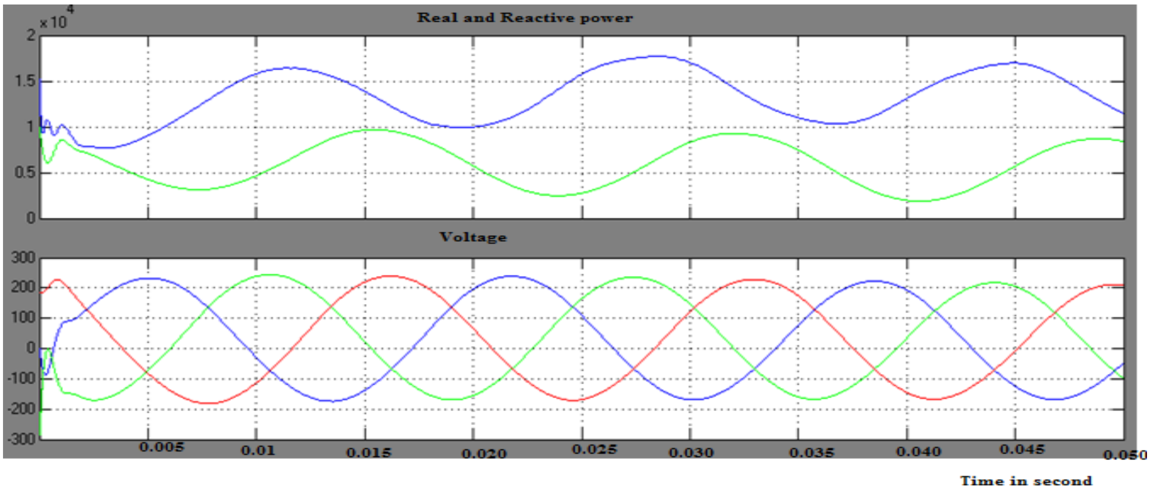

Figure A7.Waveforms of non-linear load