SIMULATION STUDY OF RENEWABLE ENERGY DRIVEN MICROGRID

RAHUL KOZHI and MEENIKUMARI
Junior Research Associate – SUPERCEN – Dr.M.G.R Educational and Research Institute – University

L. RAMESH *Member* ***IET***
Director – Sustainable Power and Energy Research Centre (SUPERCEN) – Associate Professor
Dr.M.G.R Educational and Research Institute – University, Maduravoyal, Chennai
lramesh@theiet.org , Visit @ http://www.researcherid.com/rid/A-6348-2010

Abstract: *Ever-increasing demand for energy and an increasing concern for manmade climatic changes have called for changes in the ways of electricity being generated and distributed and delivered .Micro grids are a peer-to-peer self-sustaining community Managing local generation, storage, loads, and with exclusively grid connectivity. MGs are being considered for much more than their ability to create energy islands that protect from broad power outages. Our work highlights the architecture of a MG which is driven by renewable sources which a conceptual solution for the power outages. The work begins with modeling of the following studies like, Simulation study of TNEB distribution network, Optimal placement of the Distributed sources (DG's) , Remodeling of solar PV and Wind Turbine, MG integration and reactive power compatibilities with different DG's and Voltage regulation of low voltage MG network. This low voltage distribution system is converted to MGs, having distributed generation sources (DG's), which is identified through sensitivity analysis. The modeled system tested for feasibility through several case studies.*

Key words: *Distributed generation, micro-grids, power management, wind and solar*

1. Introduction

The Micro-grids is a transformational and game changing solution in the present scenario to match the significant future energy growth. Developing a micro grid for India's power sector is a worthy challenge. It will provide revolution in the electric supply and increase the probability of achieving the Government of India's electricity goals sooner and more efficiently. Micro-grids comprise LV distribution systems with distributed energy resources (wind turbines, fuel cells, PV, etc.) together with storage devices (flywheels, energy capacitors and batteries). Such systems can be operated in a non-autonomous way, if interconnected to the grid, or in an autonomous way, if disconnected from the main grid. The operation of micro-sources in the network can provide distinct benefits to the overall system performance, if managed and coordinated.

A MG could potentially improve the technical performance of local distribution grid mainly in the following aspects: (1) energy loss reduction due to decreased line power flows; (2) mitigation of voltage variation via coordinated reactive power control and constrained active power dispatch; (3) relief of peak loading of constrained network devices through selective scheduling of nearby MS outputs; and (4) enhancement of supply reliability via partial or complete islanding during loss of main grid. When the total number of MGs reaches a sufficiently high share in LV substations, similar technical benefits can be expected in upstream grids as a consequence of multi-MG operation.[1-3]

The development of Micro Grid (MG) and its operation and control are the challenging task for the present engineers. This work aims the architecture of a MG which is working on renewable sources which a conceptual solution for the power outages. Its begin with Simulation of the MG base on real data collected from Tamilnadu electricity board(TNEB-) using power grid simulators like PSCAD . A modal MGs having 3 distributed generators (DG) connected near the load centre. A modal MG is evaluated on load flow analysis, power flow analysis, fault /year analysis, reliability assessment test .These analysis methods decides the feasibility of a simulated grid.

2. Review

Integration of various DG technologies with the utility power grid is an important pathway to a clean, reliable, secure and efficient energy system for developed economies with established levels of quality and reliability of electrical service. One notable MG demonstration project has been deployed in Uganda (Brandt 2005). It may be safely stated that technical issues related to controlling individual generators and operating a MG are far from definitively resolved. Major issues include frequency and voltage regulation; load tracking and dispatch; protection and safety; and metering and account settlement to match actual energy flows. Among these problems, foremost from an electrical engineering perspective is the local regulation of frequency and voltage in real time, which if not technically feasible renders the very MG idea moot. Ensuring frequency and voltage regulation of diverse energy sources is challenging due to their variability of dynamic capabilities. Extensive research works are presently going on in solving the modeling and control issues of MG. Most feasible five methodologies discussed below.

2.1 **Reactive power compensation management in micro-grids:**

In this paper M. R. Iravani, *Fellow, IEEE* [4], has addressed and contributes towards the problem of the reactive power and its management in a micro-grid. Due to significant line resistances in micro-grids, active power variations produced by wind turbines can lead to significant fluctuations in voltage magnitudes. This paper proposes strategies to control the reactive power of EI-DG unit. Three strategies are defined in which the reactive power of a EI-DG unit is controlled to 1) prevent deviations in terminal voltages using a pre-set V-Q characteristic achieve voltage regulation at a specific load-bus , or compensate reactive power demand of a load based on the power factor set-point of the load. These reactive power strategies are.

- *Strategy I: Voltage-Droop Characteristic:*
- *Strategy II: Voltage Regulation: Reactive power control*
- *Strategy III: Power Factor Correction*

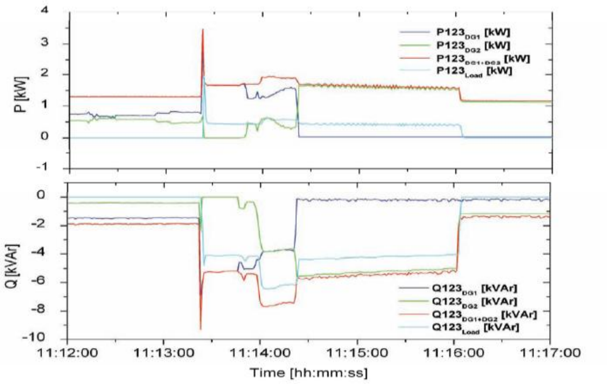

Fig 1: Output of Reactive Power

The graphical output in figure 1 shows the compensation of reactive power. The author also suggests use of droop control for the compensation of the reactive power.

2.2 Power Management Strategies for MG

In this paper Mr. F. Katiraei, *Member, IEEE*,[5] addresses the frequency restoration of electronically interfaced Distributed generation sources (EI-DG) . This paper discussed these issues in the domain of the MG. The issues are real and reactive power management strategies of electronically interfaced distributed generation (DG) units in the context of a multiple-DG MG system. The emphasis is primarily on electronically interfaced DG(EI DG) units. DG controls and power management strategies are based on locally measured signals without communications. Based on the reactive power controls adopted, three power management strategies are identified and investigated. The real power of each DG unit is controlled based on a frequency-droop characteristic and a complimentary frequency restoration strategy. A systematic approach to develop a small-signal dynamic model of a multiple-DG MG, including real and reactive power management strategies, is also presented.

Real power generation of an EI-DG unit is specified based on a frequency-droop characteristic and a frequency restoration algorithm. This method is chosen since the frequency of the MG, during an autonomous mode of operation freely varies when none of the DG units can dominantly enforce the base frequency of the system. The frequency deviations can be limited by introducing the frequency-droop characteristic that uses the MG frequency as a communication means, among the fast acting EI-DG units, to dynamically balance the real power generation of the islanded MG. During the grid-connected mode, where the frequency of the system is fixed, real power generation of the DG units is controlled by the real power references assigned to the units

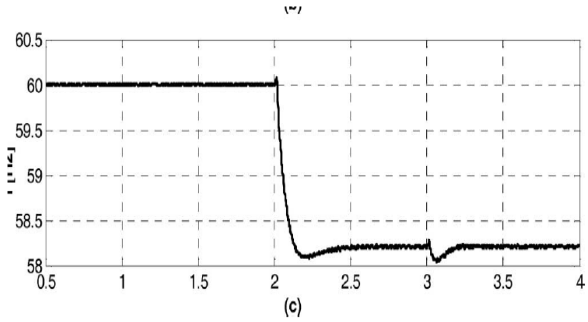

Fig 2: Output of frequency

To restore the frequency of the islanded micro-grid, the output of the frequency restoration algorithm, as shown in Fig 2 is needed. The frequency restoration term is extracted from deviations in the local frequency of the system, using a PI controller with a large time constant.

2.3 **Voltage regulation on low voltage meshed Distribution grids**

Mr.Stavros Papathanassiou[6] addresses about the benchmark setup in the low voltage MGs. MGs are foreseen within public distribution grids and therefore

in this paper suitable study case networks are required to perform simulation and analysis tasks. Moreover, standardizing study case grids to provide "benchmark" networks suitable for MG design would further enhance their merit and utility. The objective of this paper is to present and discuss a benchmark LV network developed within the EU project "MGs", Contract ENK5-CT-2002-00610 and later adopted as a benchmark LV system by CIGRE TF C6.04.02: "Computational Tools and Techniques for Analysis, Design and Validation of Distributed Generation Systems". The network consists of an LV feeder, while a more extended multi-feeder version is also included in the Appendix of the paper. The emphasis is placed on the network itself, rather than on the microsources connected and the control concepts applied. The benchmark network maintains the important technical characteristic of real life utility grids, whereas, at the same time, it dispenses with the complexity of actual networks, to permit efficient modeling and simulation of the MG operation.
He has also discussed about the general characteristics of the low voltage MGs like the Structure and the Symmetry of the configured MG.he has taken_ the study case LV feeder is illustrated in Fig.3 . The feeder is an overhead line with twisted XLPE cable, serving a suburban residential area with a limited number of consumers connected along its length, as well as at the end of the branch at its middle. Line types are marked on the diagram.

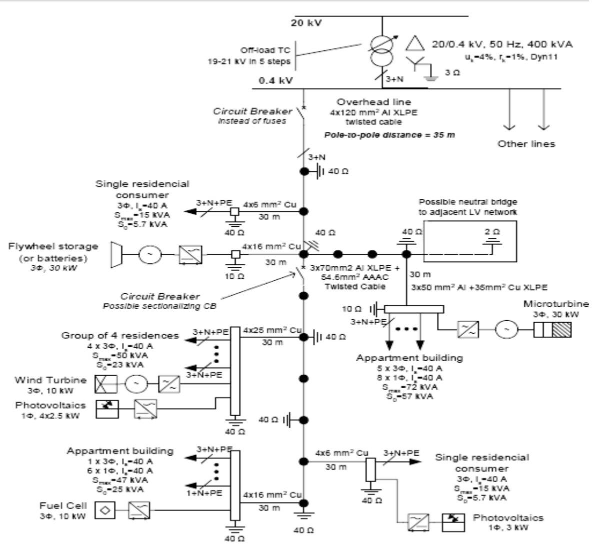

Fig 3: LV Network

In this paper a benchmark LV MG network is presented as shown in Fig 3. which is suitable for steady state and transient simulations. The study case network is based on a standard LV feeder, where micro sources and storage devices of various types are connected.

The author discuss about the some issues which he was not able to solve in this paper. That is to facilitate the simulation of multi-feeder MGs or multiple MGs within the same LV grid and the electronic interfaced Distribution generation. Specific technical details, models for individual sources and control concepts are beyond the scope of this paper and will be specified in application studies.

2.4 **Power sharing Methods of Multiple DG**
The contribution of Mr. Seon-Ju Ahn, Member, IEEE, Jin-Woo Park, Student Member, IEEE [7]the active power and frequency control principles of multiple distributed generators (DGs) in a MG. MGs have two operating modes: 1) a grid-connected mode and 2) an islanded mode. During islanded operation, one DG unit should share output generation power with other units in exact accordance with the load.

Two different options for controlling the active power of DGs are introduced and analyzed: 1) unit output power control (UPC) and 2) feeder flow control (FFC). Taking into account the control mode and the configuration of the DGs, we investigate power-sharing principles among multiple DGs under various system conditions: 1) load variation during grid-connected operation, 2) load variation during islanded operation, and 3) loss of mains (disconnected from the main grid). Based on the analysis, the FFC mode is advantageous to the main grid and the MG itself under load variation conditions. However, when the MG is islanded, the FFC control mode is limited by the existing droop controller. Therefore, we propose an algorithm to modify the droop constant of the FFC-mode DGs to ensure proper power sharing among DGs. The principles and the proposed algorithm are verified by PSCAD simulation as of fig 4.

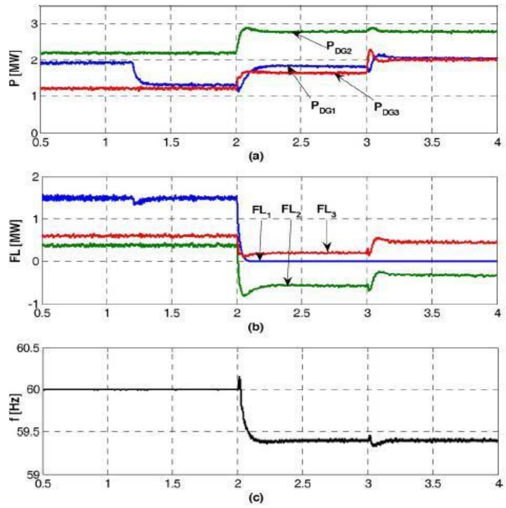

Fig 4: PSCAD Output

The power-sharing principles of multiple DGs were examined according to their control modes and configurations. The principle of the FFC mode was not as straightforward as that of the UPC mode, but it was advantageous for the main grid and the MGs.

FFC-mode DGs could automatically match the variation of downstream loads within their capacity limits during islanded and grid-connected operation Author also determined from analyzing power sharing during load variation that a configuration with multiple FFC DGs was most suitable for a MG. However, FFC-mode DGs connected in series could not share power properly with the existing droop controller during transition from grid-connected to islanded operation

2.5 **Discussion**

This report is intended as the outcome from the literature review conducted after finding documents related to our topic of interest domain 'MGs'. In most of the paper addresses following problems MG simulations, benchmark of MGs, voltage regulation, voltage droop characteristic, power factor correction, reactive power control, reactive power compensation, Power Management Strategies for a MG With Multiple Distributed Generation Units, frequency restoration, low meshed topology in different simulation platforms

The authors specifically Mr. Seon-Ju Ahn, Member, IEEE, Jin-Woo Park, Student Member, IEEE. Has stated problem of islanding but that paper strategy does not have any solution for that problem. Mr. F. Katiraei, *Member, IEEE*, also stated islanding problem but his paper majorly deals with frequency restoration using droop control. It generates some issues which are being discussed but unsolved problems in Indian context. After this flow process of literature review the generated objective stated was 'simulation of MG which is renewable energy driven and when it comes to smart infrastructures like islanding mode and operation in non-autonomous way with the electricity board'.

To relate our work with Indian context I took a LV distribution layout of Porur substation as the case study .the tool I used is PSCAD, which is a powerful and flexible graphical user interface to the world-renowned enables the user to analyze the results. Then pertinent information is repeated in the summary section for your convenience. An annotated reference list is included for ease in finding other useful guidance

3. **Methodology**

Over the course of the past century, electric power provision has transformed from small independent grids serving just a few customers to complex network served primarily by large generating plants whose power is distributed to customers via a high voltage transmission system and lower voltage distribution systems. With the ever-increasing demand of reliability, quality and efficiency of power supply, the conventional unidirectional flow of energy is slowly pointing towards the bi-directional due to the emergence of the so-called Independent Power customers. Research has successfully demonstrated the feasibility of Micro-Grids operation Producer (IPP) or Distributed Energy Resources (DERs) connected to the distribution level of the power system [8-16].

This renewed interest in distributed energy resources (DERs) has seen the emergence of new and more advanced power systems architectural concepts like "micro-grids", which can serve a small group of co-located through laboratory experiments. This concept is also proving successful from the field reports of projects like the 'More Micro-Grids' funded by the European Commission. The method of droop control as applied in voltage source inverters (VSI) which form the heart of the Micro-Grid is reviewed, especially when the Micro-Grid operates in island mode.

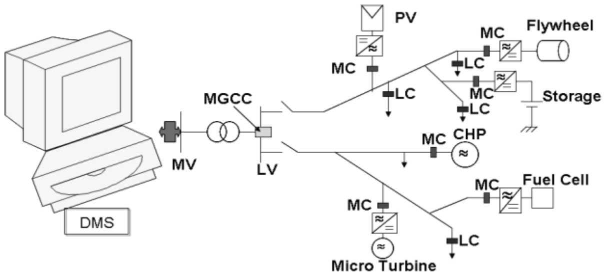

Fig. 5 : Micro-Grid with several microsources with their microsource controllers (MC),loads with their load controllers (LC),

Figure 5 showing the Micro-Grid Central Controller (CC) connected to the low voltage (LV) side of the transformer and a distribution management. System (DMS) on the medium voltage (MV) side.

Micro-Grids comprise Low Voltage distribution systems with distributed micro sources (MS) both controllable and uncontrollable, such as micro-turbines, fuel cells, PVs, etc., together with storage devices, i.e. flywheels, energy capacitors and batteries, and loads (some of them interruptible), a hierarchical type management and control scheme supported by a communication system . Such concept has been developed within the framework of the EU R&D Micro-Grids project. In this architecture, the Micro-Grid is controlled and managed by a Micro-Grid Central Controller (CC) installed at the MV/LV substation. The CC possesses several key functions and heads the hierarchical control system. In a second hierarchical control level, controllers located at loads or groups of loads – load controllers (LC) and controllers located at the micro sources – micro source controllers (MC) exchange information with the CC and control local devices. The whole system operation requires communication and interaction between two sets of devices: LC on one hand, as interfaces to control loads through the application of an interrupt - ability concept, and on the other hand MC controlling micro generation active and reactive power production level

3.1 Proposed Work

The work started with the simulation of TNEB layout and find out the optimal location to implement the DG to convert to MG. The sensitive analysis indices are used to identify the location og DG.To evaluate the performance of the proposed approach, testes have been carried out on the Indian Electricity Board, TNEB 11/.440 KV Distribution feeder. The work presents as an improved backward/ forward sweep algorithm for three-phase load-flow analysis of radial distribution systems.

The TNEB low voltage radial distribution layout of Porur garden substation is take for implementation of the approach. A transformer of 250kva with voltage ratio 11KV/440Vwhich feeds the network which is having two feeders A & B of respective load 136 KW and 148 KW. The current in both feeder is 160A and 140 A. The PSCAD is selected as simulation tool because of it is a powerful and flexible graphical user interface to the world-renowned enables the user to analyse the results

The sensitivity indices are used to identify the size and location of DG with minimum losses in distribution system. The switch topology of the controller is represented in figure 6.

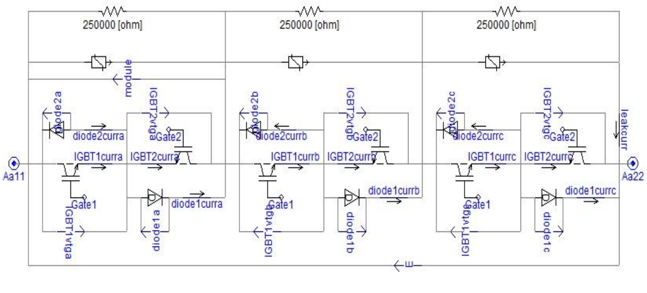

Fig 6: Switch topology

The PSCAD layout of the system is represented in figure 7 which is indexed in last page due to clarity. At terminals, A and B the all related parameter are calculated and went through comparison check for the end values of feeder. If these values are same as of the values of set of parameters at other end . When a voltage unbalance exceeds the nominal value that can be tolerated within a system as stated by the ANSI standard, some corrective action must be taken to prevent this unbalance from creating problems in the operation of the equipment inside the MG. The relay and DG setup is represented in figure 8 and 9(In last Page).

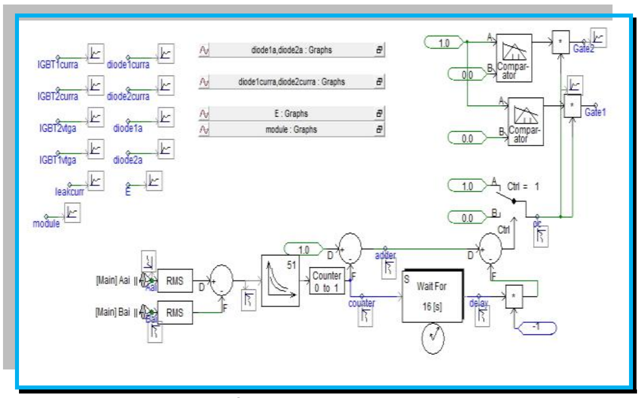

Fig 8: Relay setup for control over Grid Fluctuations

One approach could be to shut down the system . The inverter can only generate voltages on a line to line basis, so the scope of the correction would only be limited to the negative sequence. The measures of voltages and currents that are passed to the control need to be conditioned to identify the positive and negative sequence components Each of the components is then separately controlled: the positive sequence quantities are regulated to the externally requested values while the negative sequence quantities are regulated to zero. The block diagram above shows the control analogy.

The nominal grid frequency is 60Hz, but it has been measured to drift around it. Figure shows two samples of the frequency, taken less than five minutes apart. One has a –0.04Hz deviation, while the other has a +0.06Hz deviation. This frequency deviation translates in the fact that the active power may not exactly match the request.

The voltage also fluctuates of nearly 0.6 V in either direction. The setpoint of 208V is to be intended "on the average". The frequency and voltage fluctuations combined determine conditions of non-repeatability on any of the following grid connected waveforms. Different values of frequency will determine different power injections (and the following plots are recording the actual grid frequency), while different voltages at the point of connection will determine different reactive power injections. Although none of these differences are outstanding, the fact that they exist must not be forgotten when trying to reproduce "exactly" these same results.

4. Simulation Case Study

This chapter features the results based on two different case studies depend on the operation of MG. The case studies are normal operation without grid disturbance and normal operation with grid fluctuation.

4.1 **Normal Operating Condition**

The results represented in figure 10 shows the active power sharing and reactive power exchange by Micro-Grid in a case where the Micro-Grid are operated normally without grid fluctuations.

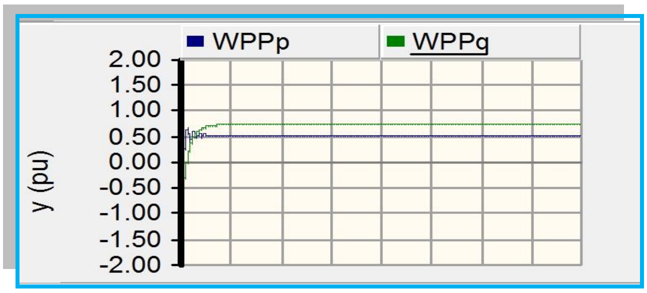

Fig. 10. Active and reactive power at the generation end in the microsources

The constant flow of active and reactive power also supports the voltage regulation. Fig 11and 12 represents the voltage and current at grid integrations.

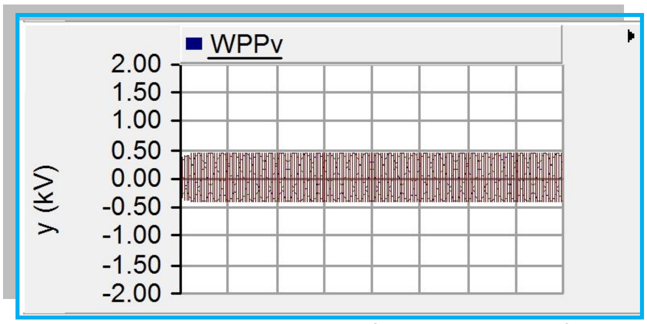

Fig. 11. Voltage at the point of grid interaction of microsource(WP)

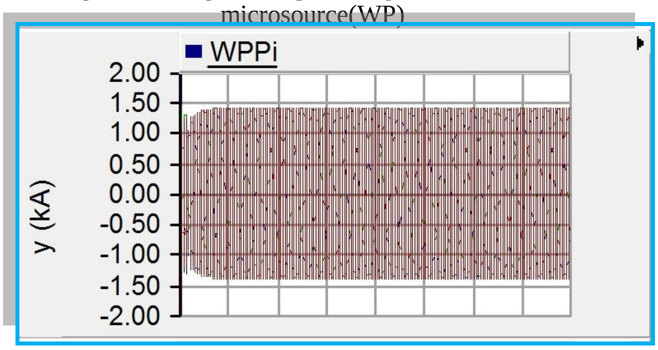

Fig. 12. Current at the grid interaction point of the microsource (WP)

The current at the point of interaction of the microsource, which is wind energy distributed generation source. It shows the regulation in the grid because of droop control Induction generator speed :

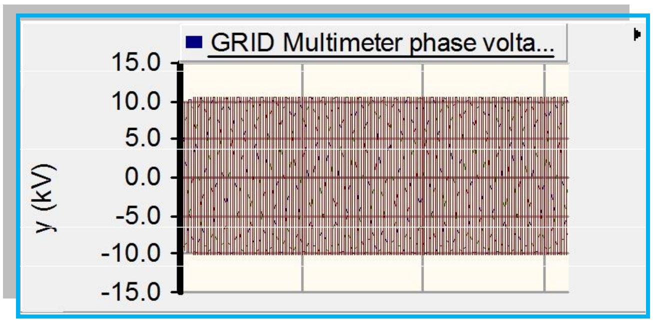

Fig. 13. Voltage in the MG measured in the TNEB network

The above figure 13 represents the voltage across the TNEB grid .Voltage control must also insure that there are no large circulating reactive currents between sources.

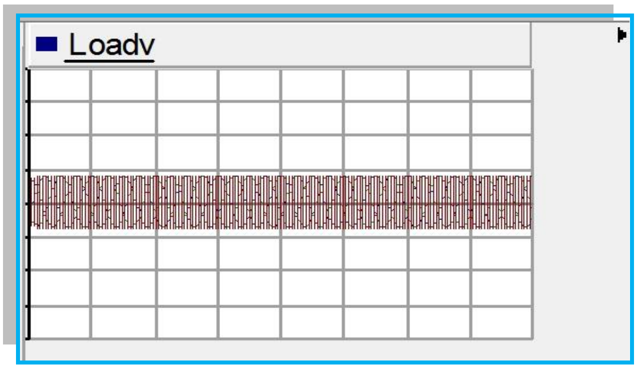

Fig. 14. Voltage across the industrial load after huge drop

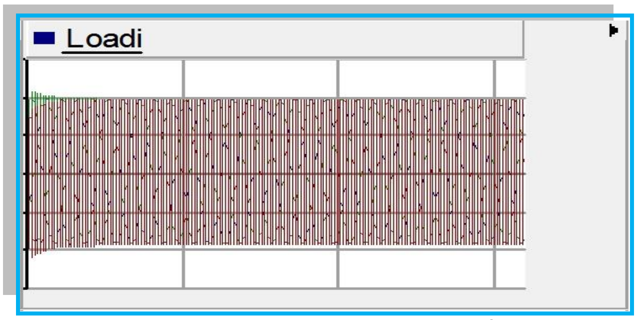

Fig. 15. Current across the industrial load after drop

The fig 14 and fig 15 shows the voltage and current across load connected to the MG.

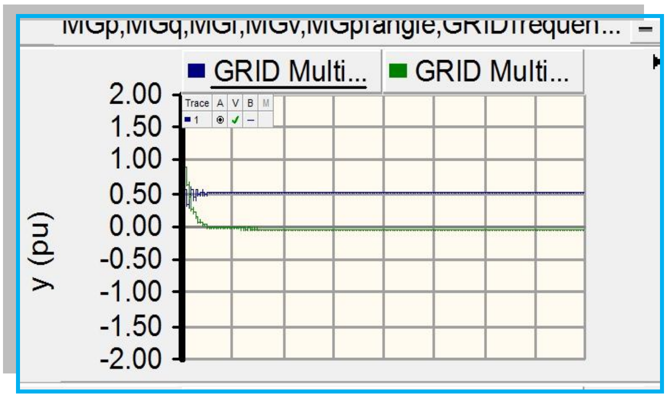

Fig. 16. Active and reactive power in the MG

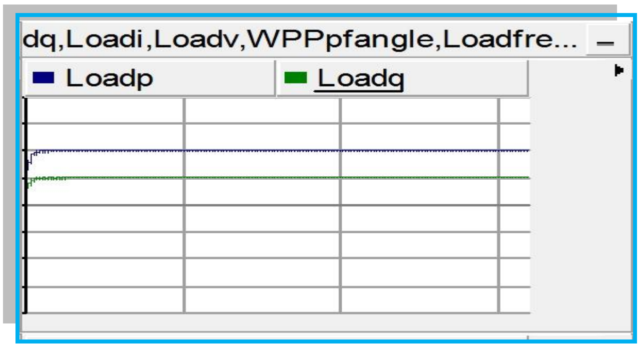

Fig. 17. Active and reactive power at the load end

Fig 16 and 17 shows the reactive power compensation at the MG and load. It shows the more percentile of active power and the reactive which required for flow of current and fault requirements. The frequency restoration is represented in figure 18.

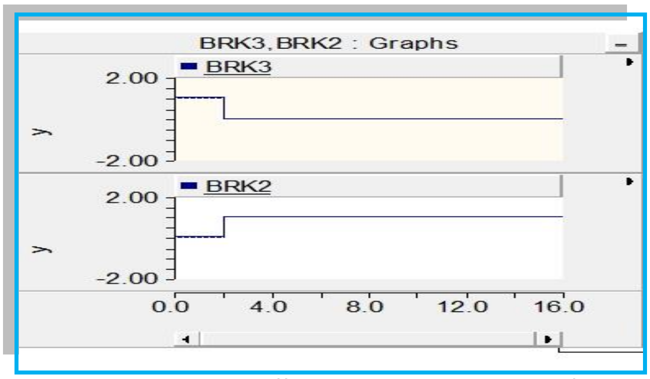

Fig. 18. The on and off switching characteristics of breakers after frequency restoration

4.2 **After grid fluctuations:**

The results of the simulation test for the active power sharing and reactive power exchange by Micro-Grid in a case where the Micro-Grid is operated normally with grid fluctuations.

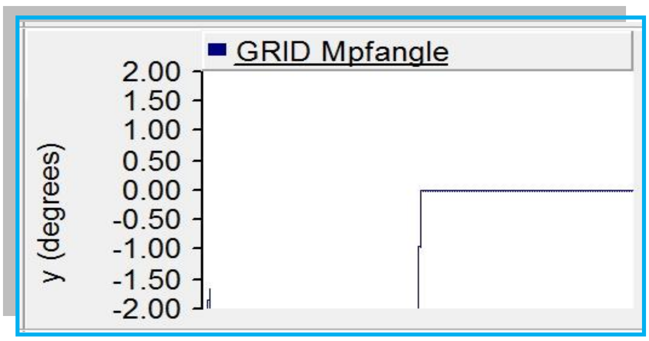

Fig. 19. The phase angle difference in the MG at two diff points A and B iin grid

Fig 19 shows When the fluctuation occurs in the grid because the change in the control parameters which works on the frequency and phase measurement. The microgris phase angle changes and it decreased down to zero degrees.

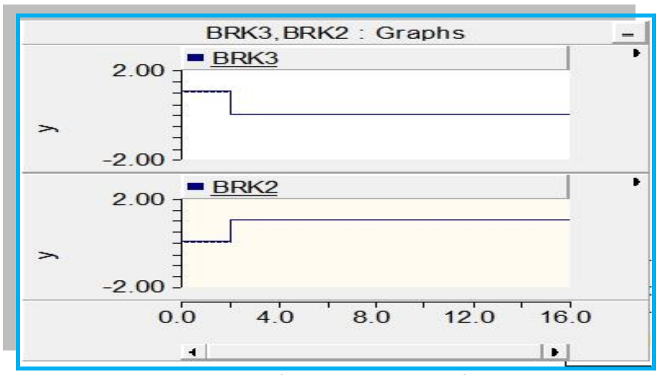

Fig. 20. The closing of circuit breaker after the grid fluctuation

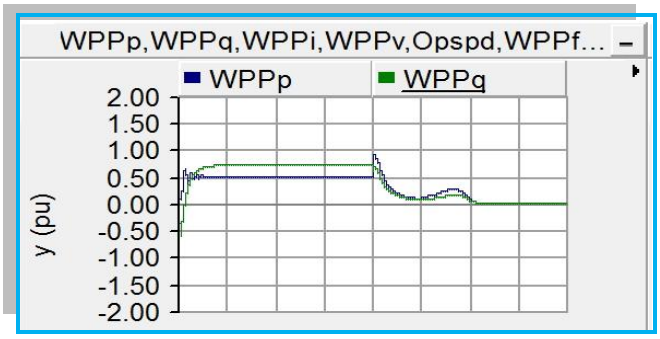

Fig. 21. Variation in the Active and reactive power at the microsource(WP)

Fig 20 and 21 shows the variation in the active and reactive power can be easily judged by the seeing the transient in the output. After the grid fluctuation the reactive power generation increases at the generation end in micro sources.

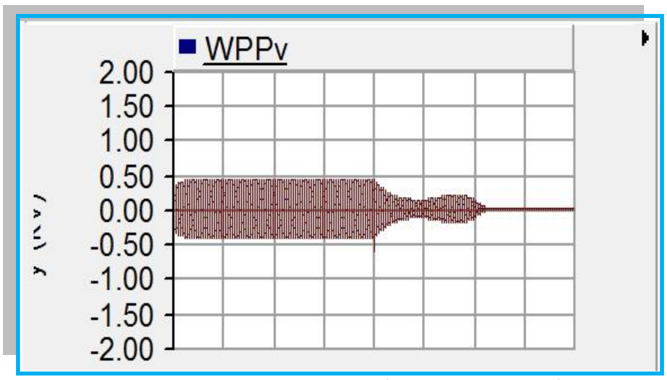

Fig. 22. Voltage during the grid fluctuation and after shut down of microsources

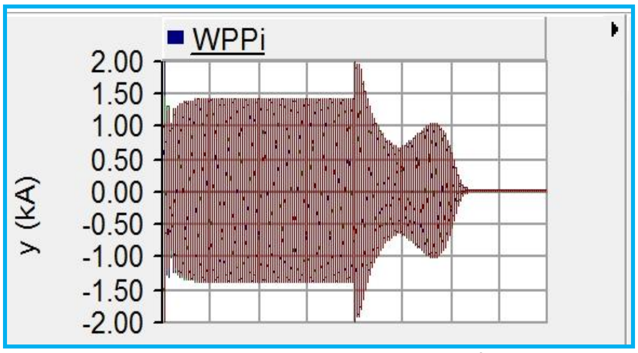

Fig. 23. Current at the generation end during fluctuations and shut down of microsources

Fig 22 and 23 shows the variation in the current at the point of interaction because of grid fluctuation which leads to shutting down of the microsources. Voltage control must also insure that there are no large circulating reactive currents between sources.

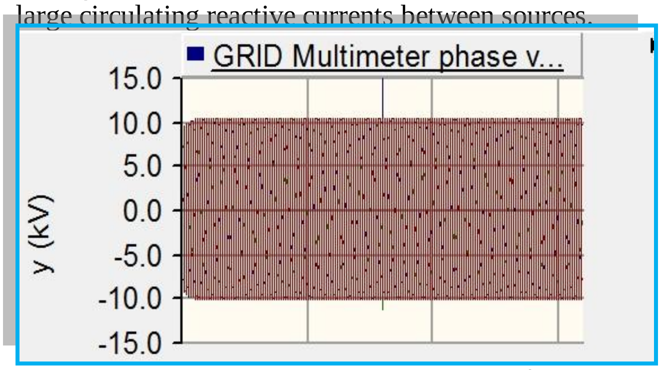

Fig. 24. Phase voltage in the grid which comes from the TNEB grid instead of microsouces of MG

Phase voltage in the domestic low voltage grid due to non-autonomous operation with the TNEB grid.

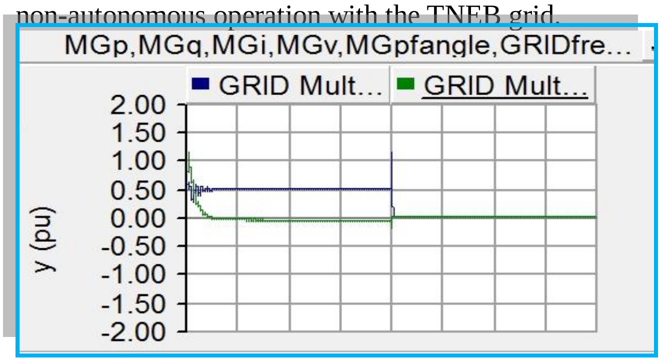

Fig. 25. Reactive power and active power sharing

This situation requires a voltage vs. reactive power droop controller so that, as the reactive power generated by the microsource becomes more capacitive, the local voltage set point is reduced. Conversely, as Q becomes more inductive, the voltage set point is increased.

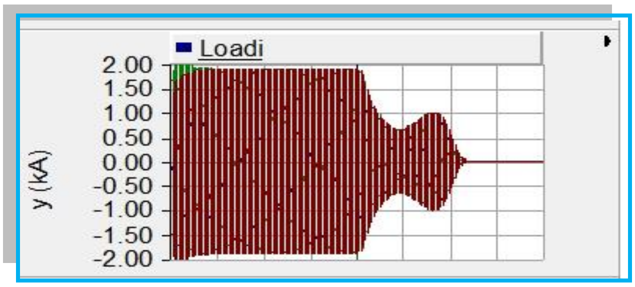

Fig. 26. Current in the industrial load which disconnected because of shut down of microsources due to grid fluctuations

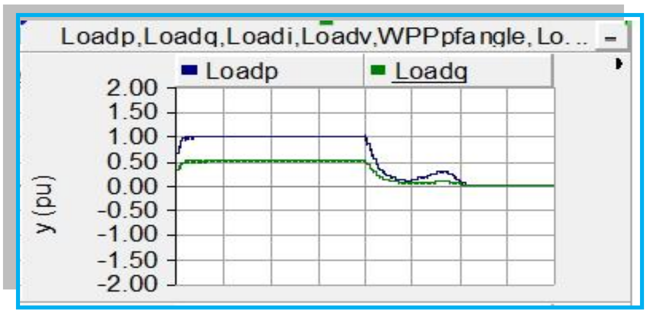

Fig. 27. Reactive power and active power analogy at the industrial load end

Integration of large numbers of microsources into a MG is not possible with basic unity power factor controls. Voltage regulation is necessary for local reliability and stability. Without local voltage control, systems with high penetrations of microsources could experience voltage and/or reactive power oscillations. Voltage control must also insure that there are no large circulating reactive currents between sources. With small errors in voltage set points, the circulating current can exceed the ratings of the microsources. This situation requires a voltage vs. reactive power droop controller so that, as the reactive power generated by the microsource becomes more capacitive, the local voltage set point is reduced. Conversely, as Q becomes more inductive, the voltage set point is increased.

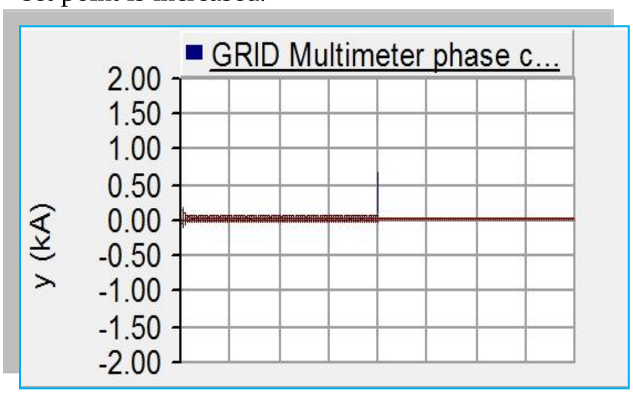

Fig. 28. Increase in the speed of the induction generator due to sudden shut down of grid on microsources

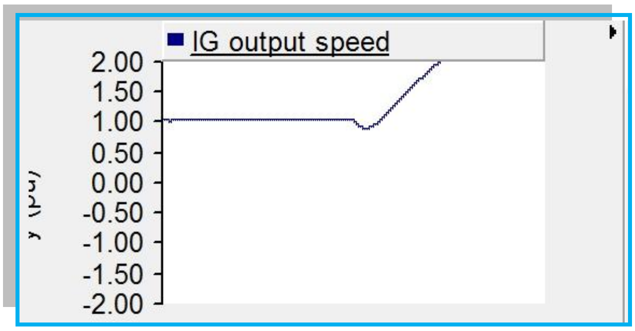

Fig. 29. Current at the grid because of TNEB grid only for household loads of KW order

It has been noted also that changes of active power demands may lead to changes in voltage and due to the voltage / reactive power droop to changes in the reactive power. In the investigated configuration, these interrelations are small; however, in other configurations the dependency may become stronger. It can also be noted from this chapter that especially for reactive type loads the droop parameters must be selected carefully in order to guarantee that the voltage stays within certain limits. In contrast to coupling of the inverters in low voltage network works, coupling of the inverters via medium voltage network requires the stronger consideration of network impendence determined by lines and transformers.

4.3 **Implementation of Standalone DG**

It is difficult to implement the proposed MG due to the heavy investment cost and control issues. The sample standalone DG system is implemented in our University (figure 30) and the one day data monitored and featured in figure 31.

Fig 30 : Implemented DG in University

The implemented system is delivering power to the EEE department research centre with online Grid connection.

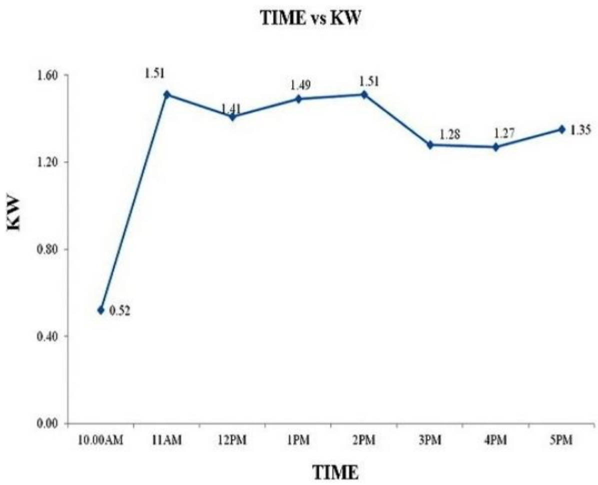

Fig 31 : DG Output for Six Hour Period

5. **Conclusion**

This work showed that the MG architecture is a viable solution for including distributed generation in a power system. This approach requires such control features for each of the units in the subsystem to operate correctly.

The widespread application of the concept of village power systems with a mix of energy sources - the hybrid power systems and Micro-Grids to the remote area electrification schemes will become technically and economically feasible only after the development of designs with improved performance that yield a definite solution. Both socio-economic and technical factors contribute to the success or failure of these systems. This work has studied a number of important factors that contribute to the better understanding of some technical and social aspects of power systems suitable for remote villages.

On the issue of voltage control in meshed low voltage grids, the work has demonstrated that this could be done by injecting some reactive power at the nearest generator nodes to the load in the low voltage meshed grid. The reactive power can be injected in a continuous way hence control the voltage in the same way unlike the discrete way in most voltage regulation devices in use presently.

For the technical viability of the intended system, the results from the measurements carried out on a microturbine operating on biogas and connected to the grid demonstrated the possible operating regimes. The microturbine are not fast enough at cold start up and thus are not suitable for UPS functions or back up for critical loads. However these are good for baseline load and are to be operated at high load

References

[1]Christine Schwaegerl Architectures and Control Concepts for More MGs Specific Targeted Project

[2]. Robert Lasseter, Abbas Akhil Consortium for Electric Reliability Technology Solutions White Paper on Integration of Distributed Energy Resources.

[3] Seon-Ju Ahn, Member, IEEE, Jin-Woo Park, Student Member, IEEE Power-Sharing Method of Multiple Distributed Generators Considering Control Modes and Configurations of a MG.

[4] F. Katiraei, Member, IEEE, and M. R. Iravani, Fellow, IEEE Power Management Strategies for a MG With Multiple Distributed Generation Units.

[5] F. Katiraei, M. R. Iravani, and P. W. Lehn, "Micro-grid autonomous operation during and subsequent to islanding process," IEEE Trans. Power Del., vol. 20, no. 1, pp. 248–257, Jan. 2005.

[6] Stavros Papathanassiou, Nikos Hatziargyriou Kai, Strunz, "A Benchmark Low Voltage MG Network" CIGRE Symposium on Power systems with dispersed generation: technologies, impacts on development, operation and performances, April 2005, Athens, Greece.

[7[Seon-Ju Ahn, Myongji Univ., Yongin, "Power-Sharing Method of Multiple Distributed Generators Considering Control Modes and Configurations of a MG" IEEE Transactions on Power Delivery, Volume:25 , Issue: 3, Page 2007-2016, july 2010

[8]Draft Application Guide for IEEE Standard 1547, Interconnecting Distributed Resources With Electric Power Systems, IEEE Std. P1547.2/D 10, Mar. 2008.

[9] M. Valenti "Reaching for 60 percent, the General Electric H turbine system taking shape in Wales is making a bid for a new record in thermal efficiency." Mechanical Engineering, April 2002.

[10] Colleen Williams, "CHP Systems," Distributed Energy, March/April 2004, pp.57-59.

[11] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, "2001 BTS Core Databook," Office of Building Technology, July 13, 2001

[12] Lasseter, R.," MGs," IEEE PES Winter Meeting, January 2002

[13] Zang, H., M.Chandorkar, G. Venkataramanan, "Development of Static Switchgear for Utility Interconnection in a MG." Power and Energy Systems PES, Feb. 24-26, 2003, Palm Springs, CA.

[14] Illindals, M., G. Venkataramanan, "Battery Energy Storage for Stand- Alone Micro-Source Distributed Generating System,“ 6th IASTED Intl. Conf. On power and Energy Systems.

[15] King, D. E., Electric Power Micro-Grids: Opportunities And Challenges For An Emerging Distributed Energy Architecture. Ph.D. Thesis, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, 2006

[16] Engler, A., Applicability Of Droops In Low Voltage Grids. International Journal of Distributed Energy Resources, Vol. 1, Number 1, January – March 2005

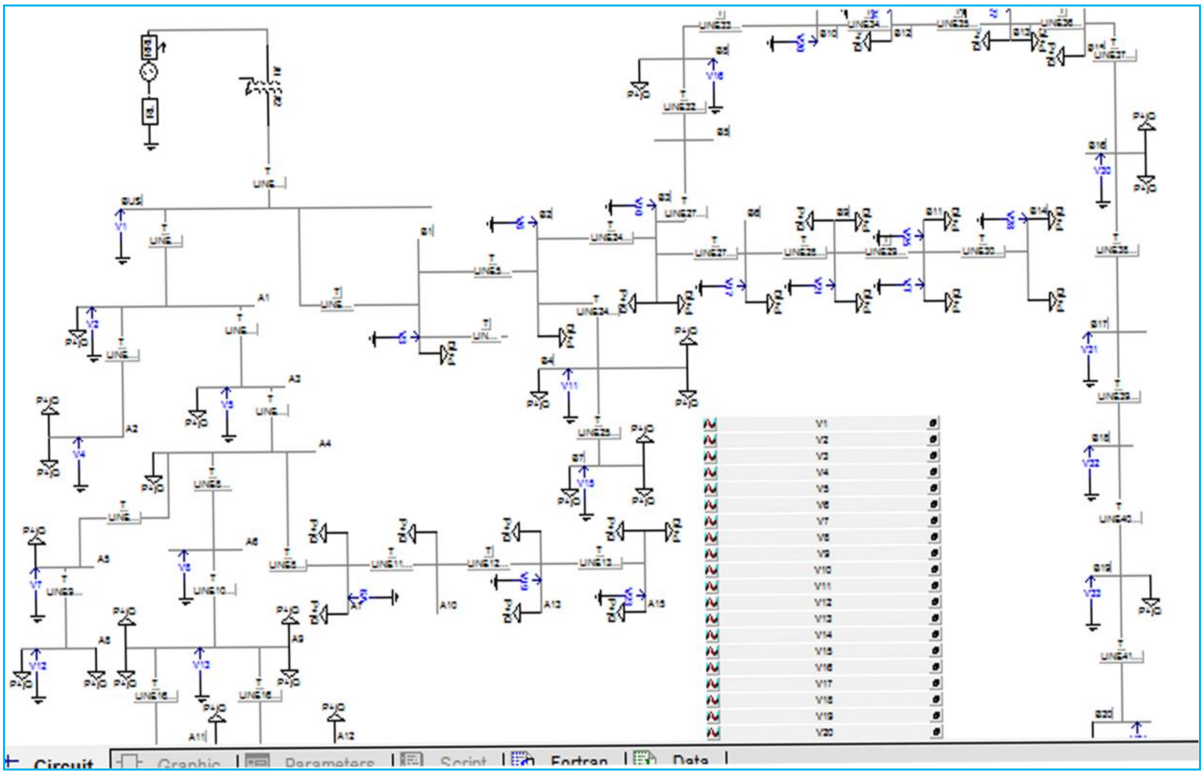

Fig 7: TNEB PSCAD layout

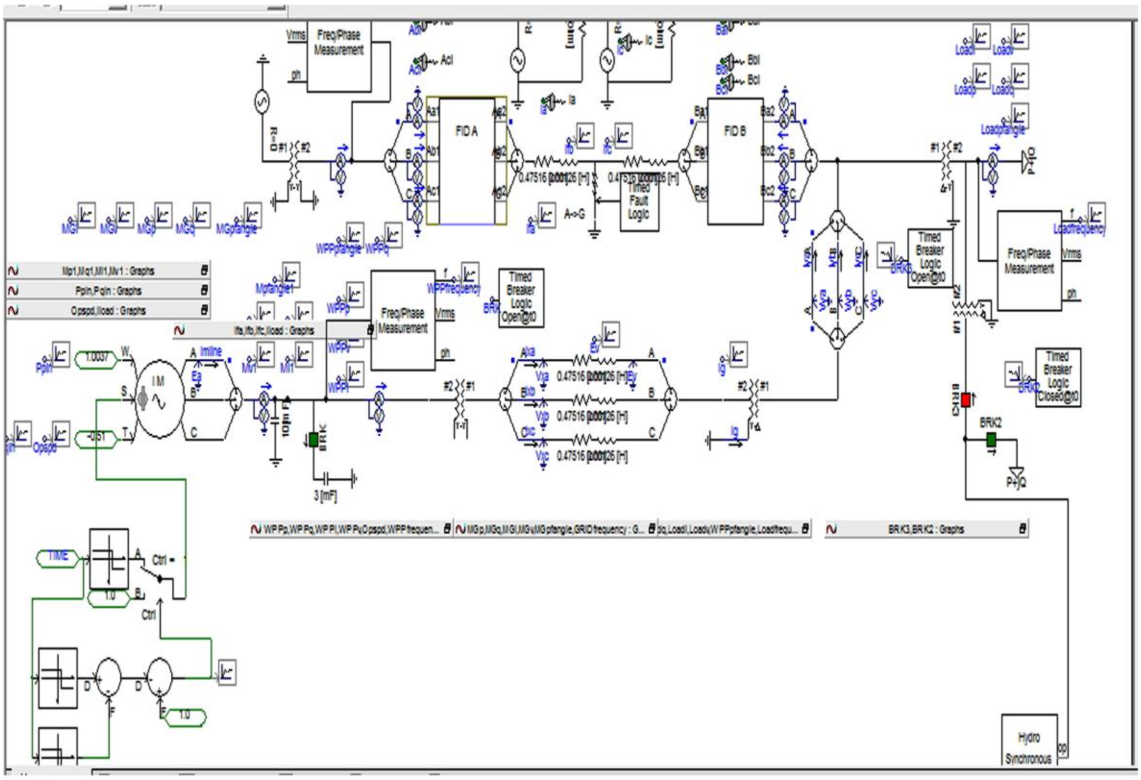

Fig 9: DG implementation and Controller setup in PSCAD