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# ARDUINO BASED EFFECTIVE DC MICROGRID POWER TRANSFER MODES

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***Abstract*— This project proposes a unified distributed control strategy for DC micro grid operating modes, without bus voltage signaling or mode detection mechanisms that are normally required for decentralized control strategies. Under the proposed control strategy, seamless mode transitions are achieved between qualitatively different operating modes, namely, 1) grid connected operation with the rectifier providing load balancing, 2) grid connected operation with the rectifier charging the energy storage systems, and 3) islanded operation. In all operating modes, the average DC micro grid bus voltage is regulated to the micro grid voltage reference, and the energy storage systems are controlled independently of the operating mode to achieve and maintain a balanced energy level. Simulations are presented demonstrating the performance of the proposed control strategy for a 380 VDC datacenter with intermittent photovoltaic generation. Hardware realization has been implemented with tiny Arduino board constructed based on ATMEGA 328 controller, whose special feature is its inbuilt ADC. The power transfer between the DC grid to AC grid and AC grid to DC grid has been implemented by checking the availability of power from renewable sources.**

***Index Terms*— ADC,VDC, micro-grids.**

## I. INTRODUCTION

Nowadays, because of high penetration levels of renewable energy resources, the paradigms of micro grids (MGs) and distribution generation (DG) are gaining vital role in power and distribution systems. MGs are categorized as ac MGs, dc MGs, and hybrid ac–dc MGs. Since a considerable portion of renewable energy resources, such as wind turbines, photo voltaic (PV), fuel cells and energy storage systems, and many modern loads such as communication technology facilities, data centers, and motor drives is dc-type, dynamics and controls of rectifiers and dc MGs are gaining high interest. However in dc grids, many generation units such as wind turbines must be interfaced to the utility grid via electronically interfaced (EI) rectifiers. In addition, several modern ac loads are coupled to ac grids through back-to-back rectifier-inverter to provide variable frequency operation.

Based on predictions given in, the resistive load share will be significantly reduced whereas the EI loads share will increase to 60-80% of the total load by 2015.The conventional control topologies for three-phase converters are the voltage-oriented vector control and direct-power control. The dq components of the current vector are regulated by a controller generating appropriate values for the converter dq voltage components.

A phase locked-loop (PLL) is required to transform current and voltage variables from the abc frame to the dq frame. It is also feasible to implement the controller in the stationary frame or the abc frame using a proportional-resonant (PR) controller. An alternative control strategy is to use direct power control in which voltage components are adjusted based on active and reactive power errors. None of these methods, however, can directly control the frequency and the load angle. One of the major challenges facing future power systems is significant reduction in grid equivalent rotational inertia due to the expected high penetration level of EI units, which in turn may lead to frequency-stability degradation. To overcome this difficulty, controlling VSCs as virtual synchronous machines is proposed for power system frequency stabilization by embedding a short-term energy storage to the VSC facilitating power flow to and from to the energy storage device proportional to the variation in grid frequency, the idea of synchronous inverters was addressed to emulate the mechanical behaviour of a synchronous generator (SG) in inverters. However, the dc-link is considered as an ideal one with infinite energy and the dynamics of dc-link voltage is not considered.

Moreover, its application to rectifiers has not been addressed. In, methods to emulate virtual inertia in VSCs interfacing wind turbines and HVDC systems are presented; however, the embedded inertia does not emulate the behavior of an SG. The analogy between voltage-source inverters and SG-based MGs has also been addressed. The aforementioned survey indicates the interest in developing new and improved control algorithms for VSCs to emulate the dynamic behavior of SGs. Beside overall low inertia, future power systems and MGs will suffer from interactions between fast responding VSCs and slower SMs which may contribute to angle, frequency, and voltage instability. With the expected high penetration level of power converters in future power grids, a power system may face severe difficulty in terms of frequency regulation because of lack of rotational inertia in converter-interfaced generators.

Another challenge is that frequency dynamics are not known in the conventional control techniques of VSCs (e.g., voltage-oriented control and direct-power control) which makes it difficult to analyze the angle and frequency stability of a system containing several EI units and conventional synchronous machines (SMs) and line-start motors. Therefore, the development of VSCs with well-defined angle, frequency, and dc-link voltage characteristics (similar to SMs with extension to dc-link dynamics) are of high interest for future smart power systems with a high penetration of VSCs. Moreover, a general control scheme which is suitable for both rectification and inversion modes without reconfiguration is very attractive in power system applications since bidirectional VSCs can work generative and motoring modes similar to SMs.

Another concern related to conventional controls is the existence of a PLL. In these controllers, a PLL is required to extract the grid angle and frequency to transform current and voltage variables from abc to dq frame and vice versa and to synchronize the VSC with the grid. However, it is well understood that PLL dynamics can affect VSC stability, particularly in weak grids. Therefore, there is a persistent need to eliminate the PLL after initial synchronization.

A power synchronization technique is proposed to remove the PLL in the steady state by a simple power loop with an integrator to adjust the VSC's angle based on real power error; in fact, this loop acts as a virtual PLL. However, this method does not exactly mimic the behavior of SMs. The concept of self-synchronization using linear controllers is discussed. Novel control strategies using nonlinear synchronizing power are addressed in to provide self-synchronization ability and large-signal stability for VSCs in MGs and very weak grid applications.

Instabilities due to dc-link dynamics are one of major sources of instabilities in VSCs. Most of previous works on virtual SGs and/or self-synchronization of VSCs consider the dc link as an ideal battery with infinite energy. However, it is obvious that this is not the case and, in most transient scenarios, dc-link voltage varies; also, its energy and power are limited. Moreover, if dc-link voltage dynamics are slow and the voltage passes some thresholds for a relatively long time, under or over-modulation and, consequently, voltage instability is expected. To improve dc-link voltage stability, fast response short-term energy storage can be installed in distributed generation (DG) units.

## II. PARAMETERS

### A. Inverter

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. There are two main types of inverter. The output of a modified sine wave inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt) and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs 5 or 10 times more per unit power (~$0.50 to $1.00USD/Watt). The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus was "inverted", to convert DC to AC.

### B. Rectifier

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components. A device which performs the opposite function (converting DC to AC) is known as an inverter. When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term *diode* and the term *rectifier* is merely one of usage, i.e., the term *rectifier* describes a *diode* that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". Rectification may occasionally serve in roles other than to generate direct current per se. For example, in gas heating systems *flame rectification* is used to detect presence of flame. Two metal electrodes in the outer layer of the flame provide a current path, and rectification of an applied alternating voltage will happen in the plasma, but only while the flame is present to generate it.

### C. Half-Wave Rectification

In half wave rectification, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a one-phase supply, or with three diodes in a three-phase supply.

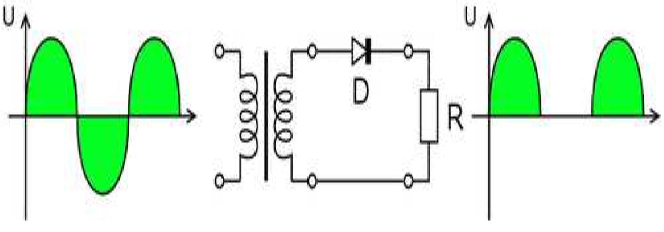


Fig.2.1 Half-Wave Rectification

The output DC voltage of a half wave rectifier can be calculated with the following two ideal equations:

$$V_{rms} = \frac{V_{peak}}{2}$$

$$V_{dc} = \frac{V_{peak}}{\pi}$$

### D. Full-Wave Rectification

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to DC (direct current), and is more efficient. However, in a circuit with a non-center tapped transformer, four diodes are required instead of the one needed for half-wave rectification. Four diodes arranged this way are called a diode bridge or bridge rectifier:

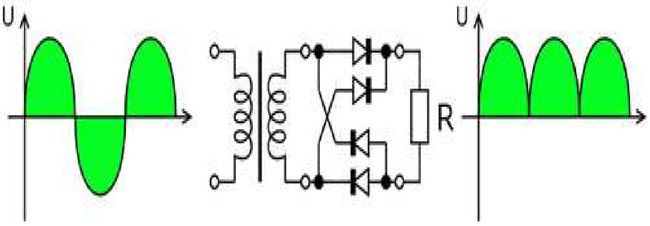


Fig:2.2 Graetz bridge rectifier: a full-wave rectifier using 4 diodes.

For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (i.e. anodes-to-anode or cathode-to-cathode) can form a full-wave rectifier. Twice as many windings are required on the transformer secondary to obtain the same output voltage compared to the bridge rectifier above.

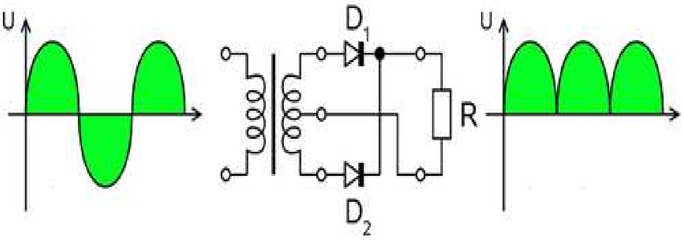


Fig:2.3 Full-wave rectifier using a transformer and 2 diodes.

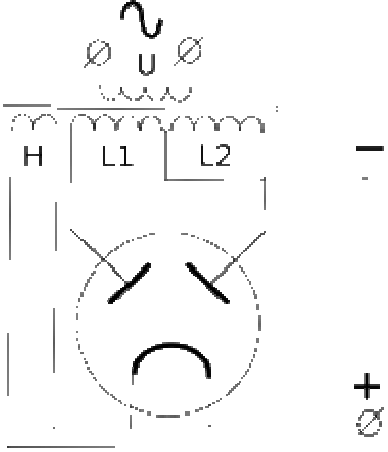


Fig:2.4 Full-wave rectifier, with vacuum tube having two anodes.

A very common vacuum tube rectifier configuration contained one cathode and twin anodes inside a single envelope; in this way, the two diodes required only one vacuum tube. The 5U4 and 5Y3 were popular examples of this configuration.

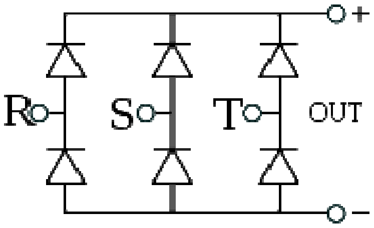


Fig:2.5 A three-phase bridge rectifier.

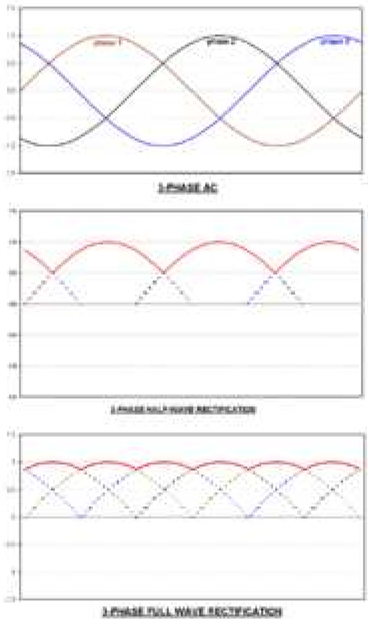


Fig:2.6 3-phase AC input, half & full wave rectified DC output waveforms

For three-phase AC, six diodes are used. Typically there are three pairs of diodes, each pair, though, is not the same kind of double diode that would be used for a full wave single-phase rectifier. Instead the pairs are in series (anode to cathode). Typically, commercially available double diodes have four terminals so the user can configure them as single-phase split supply use, for half a bridge, or for three-phase use. Most devices that generate alternating current (such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.The average and root-mean-square output voltages of an ideal single phase full wave rectifier can be calculated as:

$$V_{dc} = V_{av} = \frac{2V_p}{\pi}$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

Where:

$V_{dc}$,$V_{av}$ - the average or DC output voltage,
$V_p$ - the peak value of half wave,
$V_{rms}$ - the root-mean-square value of output voltage.
$\pi = \sim 3.14159$

### *E. Peak Loss*

An aspect of most rectification is a loss from the peak input voltage to the peak output voltage, caused by the built-in voltage drop across the diodes (around 0.7 V for ordinary silicon p-n-junction diodes and 0.3 V for Schottky diodes). Half-wave rectification and full-wave rectification using two separate secondaries will have a peak voltage loss of one diode drop. Bridge rectification will have a loss of two diode drops. This may represent significant power loss in very low voltage supplies. In addition, the diodes will not conduct below this voltage, so the circuit is only passing current through for a portion of each half-cycle, causing short segments of zero voltage to appear between each "hump".

## III. OPERATING PRINCIPLE

The present system consists of ac and dc grid systems. Both equipped with a bidirectional ac to dc converter. This enables the loads to bet power supply irrespective of shortage in power, with some constraints.

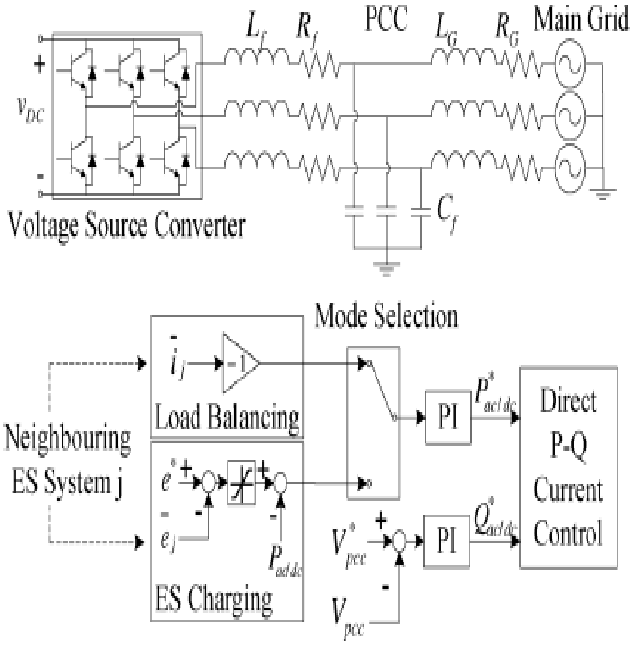
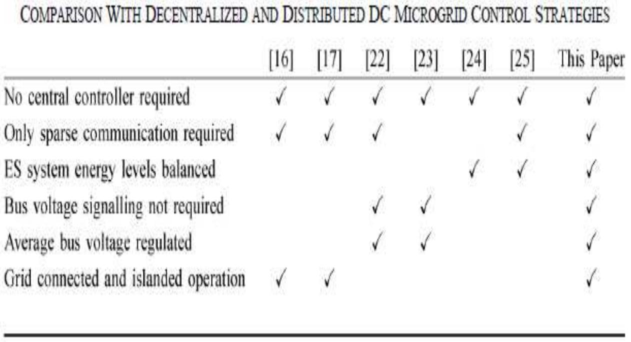


Fig.3.1.Controller Design

Load balancing and energy storage charging are done with two different PI controllers. Needs timely change of control based on the two modes. LCL filters have not been optimized.



COMPARISON WITH DECENTRALIZED AND DISTRIBUTED DC MICROGRID CONTROL STRATEGIES

| | [16] | [17] | [22] | [23] | [24] | [25] | This Paper |
|---|---|---|---|---|---|---|---|
| No central controller required | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Only sparse communication required | ✓ | ✓ | ✓ | | | ✓ | ✓ |
| ES system energy levels balanced | | | | | ✓ | ✓ | ✓ |
| Bus voltage signalling not required | | | ✓ | ✓ | | | ✓ |
| Average bus voltage regulated | | | ✓ | ✓ | | | ✓ |
| Grid connected and islanded operation | ✓ | ✓ | | | | | ✓ |

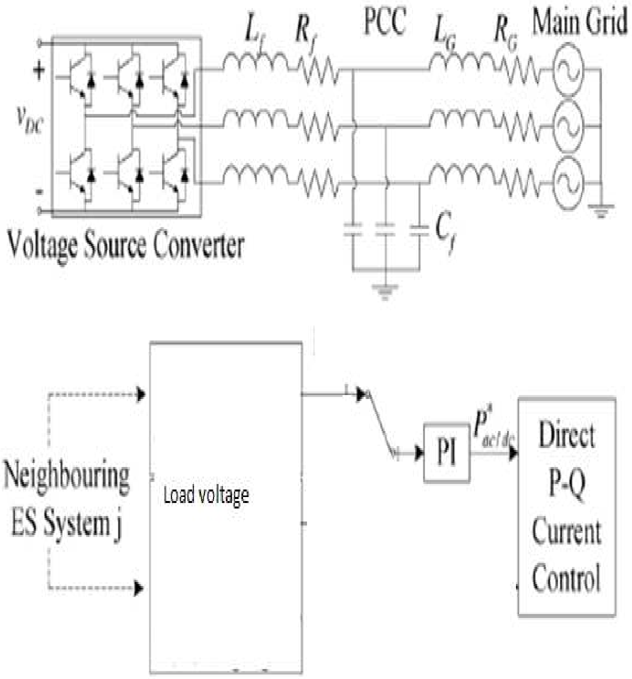


Fig.3.2. Block diagram of proposed control system

The proposed control strategy is based on the novel integration of distributed controllers for energy balancing between ES systems with distributed controllers used to regulate the average DC micro grid bus voltage, and a new method for controlling the grid connected rectifier that maintains the distributed control structure with only one PI controller to handle two different modes of such as load balancing and energy storage systems. Promising directions for future work include the extension of the proposed control concept to DC micro grids with a mix of different storage device technologies, and detailed investigation into the implementation of the communications network such as zigbee or wifi. 4 DG system with 4 energy storage system with grid connected mode and stand alone mode. Optimizing the LCL filter to reduce power imbalances. To reduce the effect of communication delay due to wifi or zigbee modules.

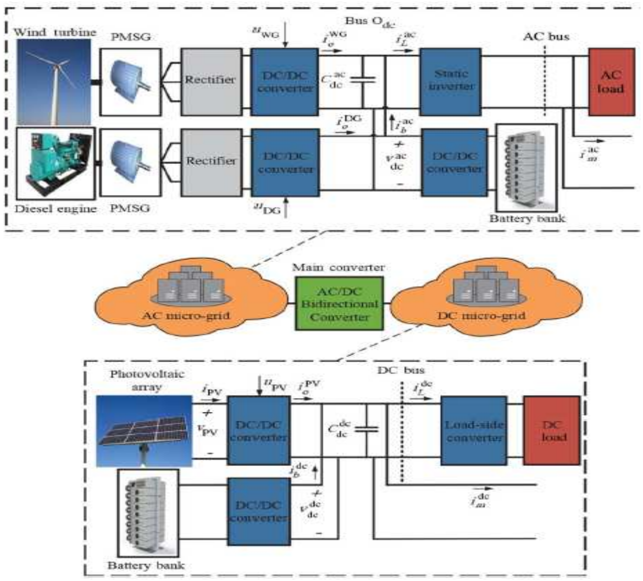
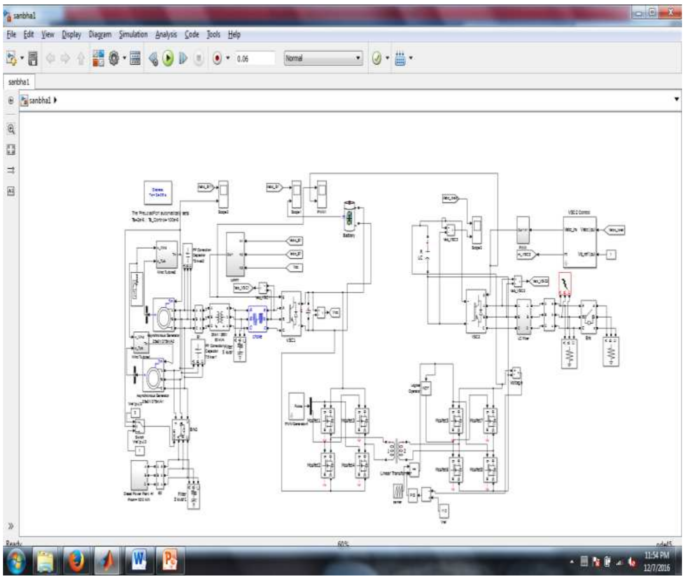


Fig.3.3 Block Diagram Of Proposed System

We do optimization process earlier (using less number of feature dimensions). A wireless based trigger is enabled to initiate the power transfer and hence it is not affected by any physical damage of signal transmission lines.

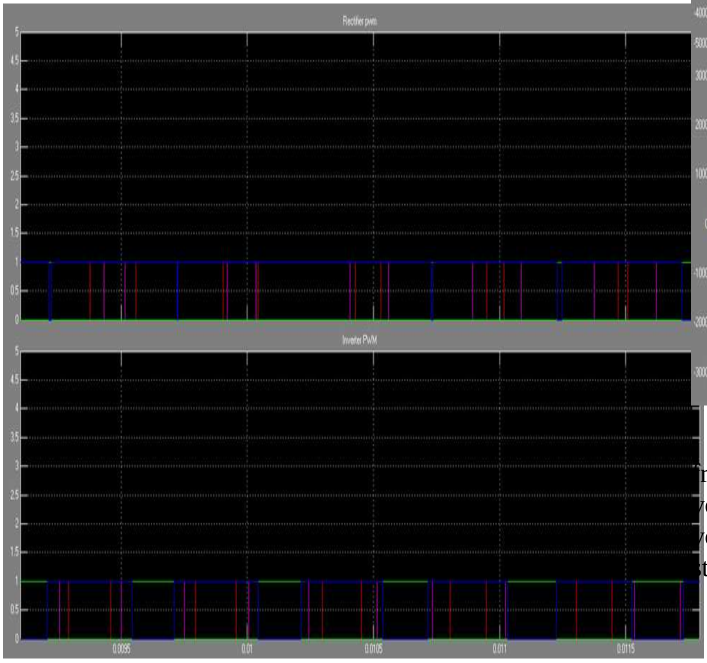
## IV. SIMULATION RESULTS

### *A. Forward AC Grid*



The above Simulink model shows the power generation using wind, diesel in the forward direction. The power generated is converted into DC and the same is stored in the form of DC in a backup battery. The bidirectional DC-DC converter allows the power flow in both the directions. Hence, either Ac grid or DC grid would get power based the power demand and the availability.

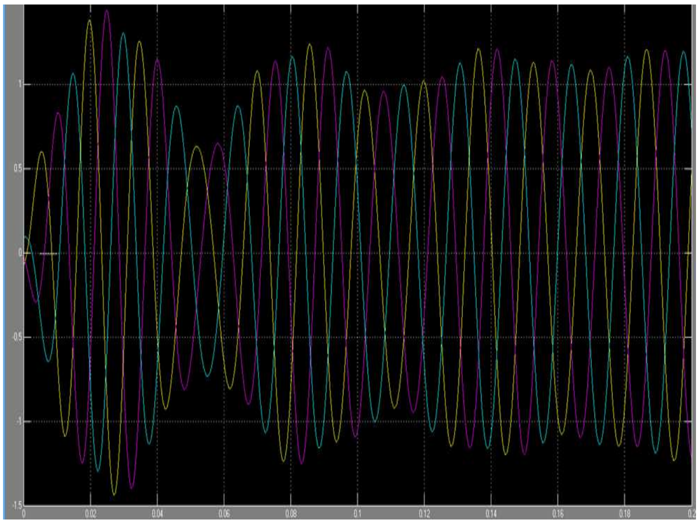
### *B. PWM Pulses*



X axis – time in sec
Y axis – Voltage amplitude (pulse amplitude of 0 V to 1 V)

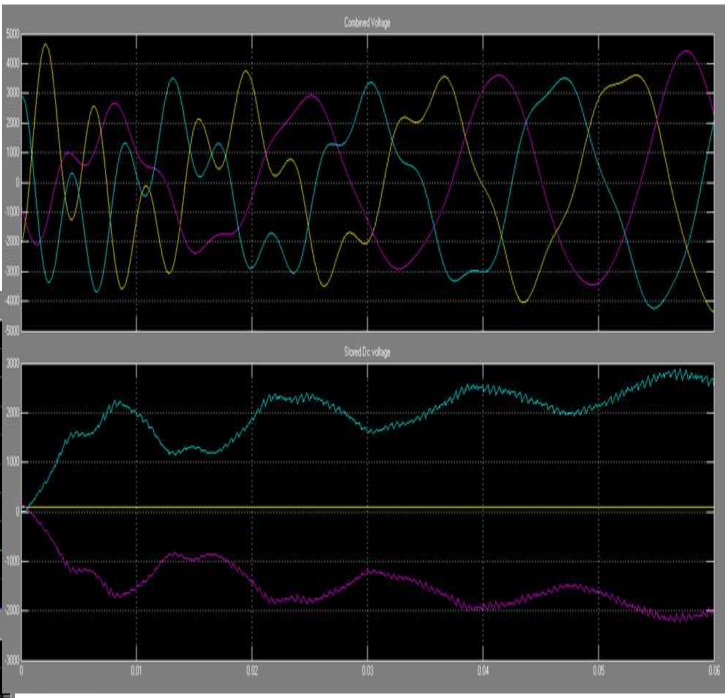
These pulses are applied to 6 switches of three arms constructed using MOSFETs.

### *C. Only From One DG*



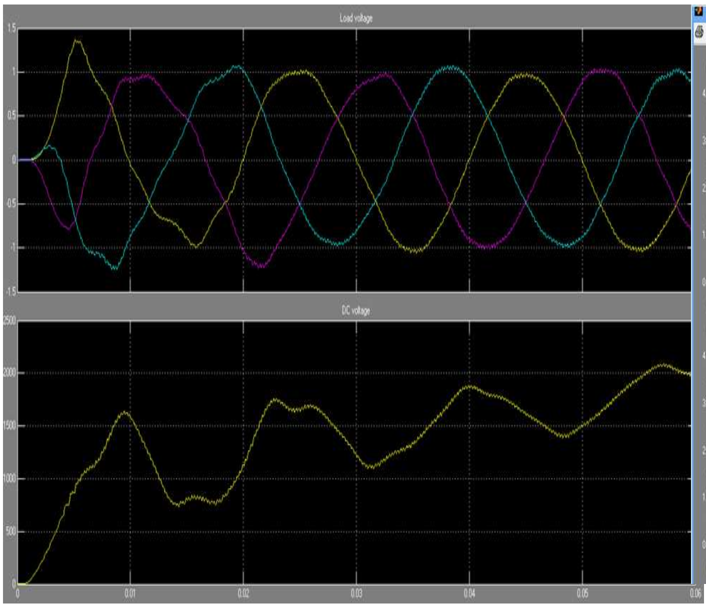
The Stability takes at least 0.14 s to settle down. After that the diesel generator produces a constant voltage and hence the constant power.
X axis – time in sec
Y axis – Voltage amplitude

### *D. Generated Voltage And DC Stored Voltage*



This output shows the three phase voltage generated rom a combined diesel and wind source along with the DC oltage stored in the battery at DC side. The settling of oltage waves to stable values takes at least 0.05 s to give a table voltage.

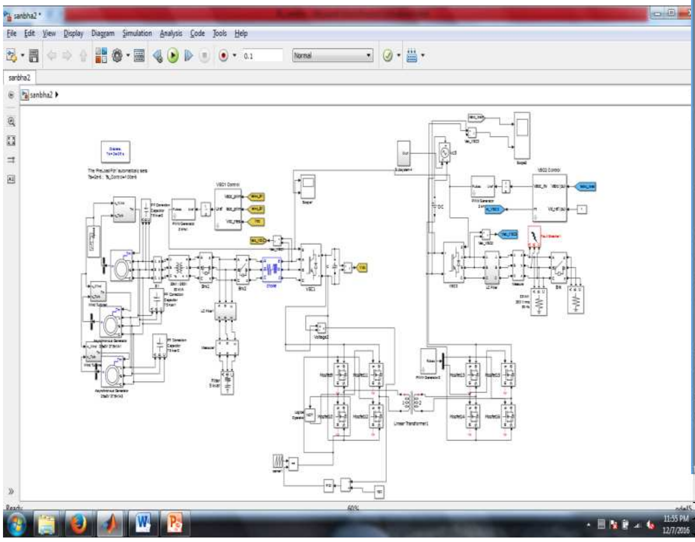
### *E. Load Voltage*



X axis – time in sec
Y axis – Voltage amplitude

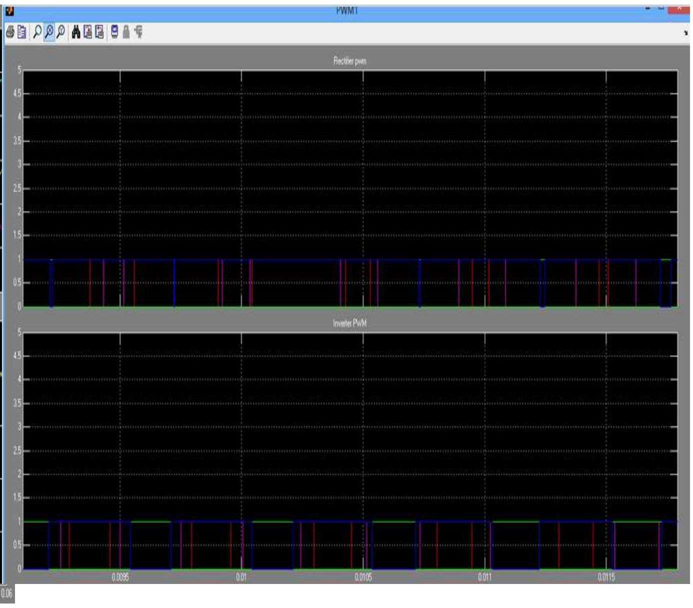
This output shows the three phase voltage at a three phase load supplied from a combined diesel and wind source along with the DC voltage stored in the battery at DC side. The settling of voltage waves to stable values takes at least 0.05 s to give a stable voltage.

### *F. Outputs in DC Grid Side*



The above model shows the reverse power flow from DC to AC side. Where the breakers are programmed to allow only the DC power and blocks the AC power to the load placed at the AC grid side. The power generated from solar panels and already stored in the batteries are transmitted in reverse direction via a bi directional dc-dc converter and hence that is inverted and supplied to the three phase load after a proper LC filter to convert into a pure sine wave.

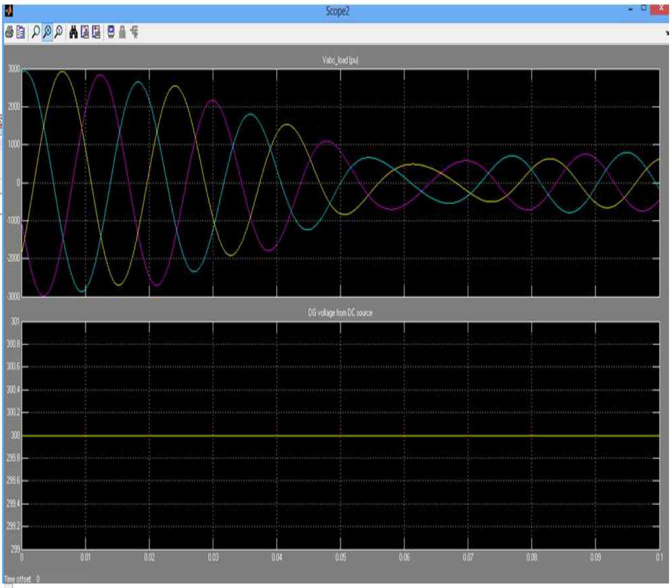
### *G. PWM Pulses*



X axis – time in sec
Y axis – Voltage amplitude (pulse amplitude of 0 V to 1 V)

These pulses are applied to 6 switches of three arms constructed using MOSFETs. The pulses remain the same in both forward and reverse is the feature of our work.

A) Load voltage at AC side and DC voltage at DC grid side



X axis – time in sec
Y axis – Voltage amplitude

This output shows the three phase voltage at a three phase load supplied from DC grid along with the DC voltage stored in the battery at DC side. The settling of voltage waves to stable values takes at least 0.07 s to give a stable voltage. The settling time depends on the controller efficiency. The DC voltage shown in the figure is the summation of the solar panel and the battery voltage.

## V. CONCLUSION & FUTURE WORK

A unified distributed control strategy for different DC micro grid operating modes has been proposed. The proposed control strategy is based on the novel integration of distributed controllers for energy balancing between ES systems with distributed controllers used to regulate the average DC micro grid bus voltage, and a new method for controlling the grid connected rectifier that maintains the distributed control structure. The distributed control structure offers advantages in terms of robustness, extensibility and flexibility over centralized control strategies, since only a sparse communication network is required between the energy storage systems and grid connected rectifier. The main advantages of the proposed control strategy are that the average DC micro grid bus voltage is regulated during all modes and mode transitions and the energy storage systems achieve a balanced energy level and maintain it through accurate load sharing, independently of the operating mode. Simulations have been carried out demonstrating the performance of the proposed control strategy for a 380 VDC datacenter with intermittent renewable. Hardware implementation is done successfully based on ATMEGA 328. Bidirectional flow of power from micro grid to macro and from macro grid to micro grid is successfully verified based on the available conditions. Thus various operating modes have been verified based on power saving architecture.

The project may be used as a centralized controller to maintain all the buses included in the grid. Presently the scenario has been explained for few buses. Any further optimizations may be included in this work in order to have robust control over power quality parameters. (presently power quality parameters have not been addressed). The system may be designed as an embedded hardware in order to convert all control algorithms into VLSI based control. Power level may be increased in order to check the robustness of the control algorithms. A prototype may be designed to induce a variable voltage fault, and to make it stable instead of its oscillations. A micro controller is used to control the voltage while sensing the voltage through a potential transformer for a single phase load. Additional power saving can be done using some digital lighting addressing schemes in order to improve the power saving

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