# CONTROL STRATEGY FOR MODULAR STRUCTURED RENEWABLE DC MICRO-GRID

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## 1. Executive Summary

In rural areas, deserts, mountainous and less populated regions, proper-grid supply will be too costly due to rough countryside terrain and topography. In such situations, renewable energy sources of solar and wind can be integrated together into a local power supply. The integration of such sources at the distribution level is called Distribution Generation (DG). Challenges in such applications will be the stability of the sources by making them to load variation requirement, which will necessitate storage of required amount of energy over a given sequence of hours. As AC can not be stored, the AC from wind be converted into direct current as a DC bus bar, stable voltage levels of which is a challenging requirement. Also, when integrated with normal grid supply, there are system disturbances which could be challenging as well [1, 2]. In such applications scenarios, DC/AC and AC/DC converters are frequently used, some of the structured in modular structured fashion for easy expansion and maintenance reason.

Modular structured inverters are commonly used in DG, and have been becoming new trend for getting power from Renewable Energy Sources (RES). RES of solar photovoltaic (PV), wind turbine, fuel cells and micro-turbine are integrated making it like a grid-system at the distribution level. DG has been becoming an attractive solution due to many economic and environmental advantages as it integrates diverse DC or AC Renewable Energy Sources. The DG system consists of micro-grid, energy storage systems, its local loads, and a chain of converters (DC/DC, DC/AC, AC/DC) for connection to main AC grid supply system [3-7]. However, a DC micro-grid is thus performing better than AC micro-grid, as it does not have issues related to reactive power, synchronization and losses associated with skin effect. Such DC micro-grids are coming very fast in those areas inaccessible to normal grid supply. The same is true for situations in the underdeveloped and developing worlds alike. In the developed world's even, metropolitan cities are destined for electric vehicles (EVs)-based transport system with micro-grids taking shapes of DC points for EVs battery packs charging purposes. Also, providing sizeable part in the not very far off future such DG interconnection will be used in some kind of load balancing mechanism in grids, which are in the process of gradual, e.g., 30-50%, RES penetration [2, 8, 9]. Figure 1 shows a typical block diagram of one such inter-connected micro-grids system. The scope of work of this research is related to what is enclosed in the dotted colored box.

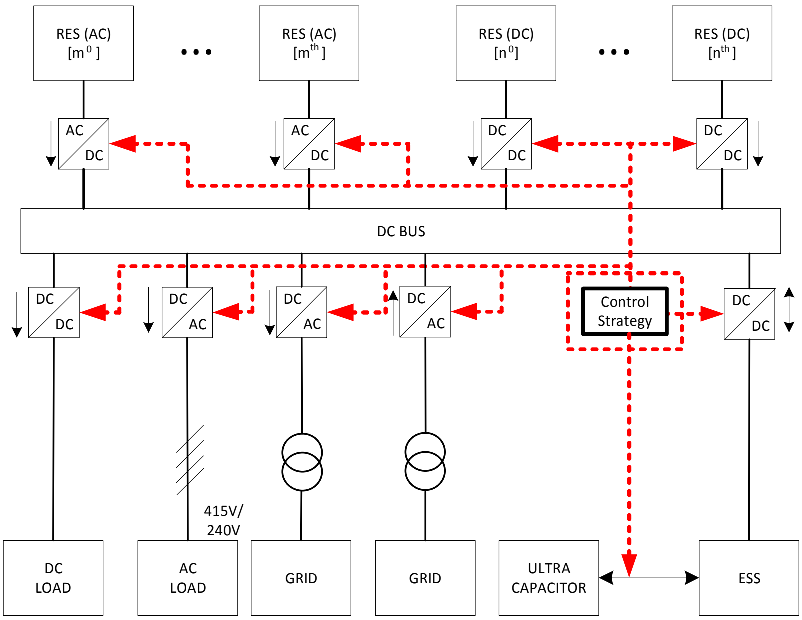



Figure 1: Micro-grid Interconnected System For Stable Supply System

## 2. Literature Review

DG employs bringing together renewable sources in the form of what is called micro-grid for connectivity to national grid supply at the distribution level low-voltage. DG can be standalone, however in integrated fashion it may involve diverse sources of solar, wind, micro-turbine, fuel cells or even oceanic tidal power for supporting the main supply system[10]. The trend of DG is on the rise because of mainly two reasons—namely, 1) renewable energy products have been becoming affordable, and 2) changing living style priorities by the environmental groups for pollutants minimization [11, 12].

The DG has got its merits of the available energy assets utilization, enhanced power quality, and better system reliability, flexibility, and capacity using modular structures in well-connected fashion. Such structured approaches of DG give rise to what is known by the name of micro-grids. Micro-grids may have their own loads (DC or AC) before they are integrated to national grid systems. Micro-grids have the preferential benefits of being islanded and isolated easily in the case of disturbances as a result of accidental or transitional conditions on the main grid system.

There are several challenges to be addressed, such as power sharing, bus-bar voltage regulation, the analysis of circulating current, and minimizing harmonic in currents [5, 13]. Thus, the need of more and more renewable energy penetration at DG level, solving the issues of power sustainability, however DG comes with problems related to quality. It is mainly due to injection of more harmonics leading to having voltage distortion, particularly when the inverters do not comply standard procedures of harmonic elimination [14]. The issues related to load sharing and voltage regulation have been becoming the main focal subject. Such problems are explored through appropriate modelling of PV systems. Other common problems as a result of reactive power injection, are addressed through the use of power factor correcting circuits [15]. Meanwhile converters of varying requirement types are employed for issues related to voltage levels, power factors, and regulated voltage levels of DC bus bars. In the case of micro-grid from diverse sources renewable energy systems, optimal scheduling and energy management of standalone or grid-connected sources is gaining serious attention of researchers. Such integrated scenarios of DG system-connected networks are influenced by disturbances such as voltage dips (sags) or frequency shift, which are system problems affecting stability of DG. Such issues have been becoming of high concerns from research viewpoints, and are addressed from various aspects in the form smart converters [16, 17].

While in the islanded mode, the system needs to control the sharing load with different units and to balance the power in the micro-grid. To achieve this is by using the centralized or decentralized power management [17-22]. The centralized method of control strategy will rely on the communication between energy sources and the loads, which reduce the reliability of the system [16, 23]. Decentralized control method however requires local measurements and also the non-crucial communication can be used in order to achieve other objectives such as restoring voltage and frequency disturbances.

The contemporary reported research work is tabulated in Table-1 as critically analysed review.

Table 1 Comprehensive Study on Micro-grids

| No | Paper Title | Contributions | Limitations |
|---|---|---|---|
| 1 | “Development Of A Control Strategy For Interconnection Of Islanded Direct Current Microgrids” [27] | Proposes a control strategy of the Bi-Directional Converter for interconnecting two micro-grids operating at different level of DC voltages. | It limits for two micro-grids operated in islanded mode. |
| 2 | “A Novel Frequency and Voltage Control Method for Islanded Microgrid Based on Multienergy Storages” [20] | Proposes a control method for Energy Storage System based Micro-grids that providing the frequency and voltage determined by the actual active power and reactive power.<br>It will maintain the stability of the frequency and voltage through the right active power and reactive power distribution. | The operation of an autonomous Micro-grid is usually more complex than grid-connected.<br>For low/medium voltage Micro-grids, traditional droop method is invalid due to the real and reactive power coupling among ESS and will deteriorate system transient response and steady-state performance.<br>Moreover, the control process in this situation becomes complex due to the uncertainty of line impedance and control parameters. |
| 3 | “A Voltage and Frequency Droop Control Method for Parallel Inverters” [23]” | The classical droop method provides the good performance under all circumstances with benefit of preventing the low voltage cables grid.<br>The propose technique more efficient to control the frequency and voltage in proportion to the needed active and reactive power flows. | Limited by a voltage source with a complex finite-output impedance<br>This method also depends on the difference between rated and actual grid frequency. |

| | | | |
|---|---|---|---|
| 4 | "Frequency Based Energy Management Strategy for Stand Alone Systems With Distributed Battery Storage"[16] | Proposes an energy management strategy for a multiple-battery system with no need for communication cables between inverters or with a central supervisor with the protection during the battery charging. If the batteries are fully charged or are absorbing too much current, then the grid frequency is increased, which is measured by the inverters and later reduce the power in order to control the battery voltages or currents. | All the batteries will need to be regulated once they reach the minimum voltage in order to prevent the damages of the batteries. |
| 5 | "A Control Strategy for a Distributed Power Generation Microgrid Application With Voltage and Current Controlled Source Converter" [17] | Proposes a new control method based on the micro-grid line-frequency variation as the agent of communication for energy control among the power distribution modules. | Micro-grids need to be operated in islanded or grid connected, but the challenges of the droop control method as well as the utility grid system.<br><br>The effectiveness has not been demonstrated with higher penetration of power distribution or control nuisance due to transient effects within the micro-grid structure. |

## 3. Problem Statement and Definition

An integrated Distributed Generation (DG) made from diverse Renewable Energy Sources (RES) is sustainable, provided it is kept at stable voltage supply. It is already flexible as it can be easily expanded due to its modular structure. It can be integrated with main AC grid supply for power import and export purposes. Such interconnected system of renewable energy sources is called micro-grid, consisting of DC/DC and DC/AC or AC/DC converters. One of the major problems faced by power supply companies these days is that electricity cannot be stored easily; rather it needs be used as immediately as it is generated [9, 25].

Hence such system lack from the capability of responding to emergency situations of voltage and frequency fluctuations. One way to reduce these fluctuations could be through the use of an Energy Storage System (ESS) supported by using the ultra-capacitor component [26, 27]. There is thus the need of a control strategy for checking on the flow of energy from RES onto the ESS, and from ESS onto the loads or for sending it out to grid or importing energy from the grid.

This work is based on the further part of what is already covered in recent articles [28, 29] by suggesting a controlling mechanism, making sure better stability, more availability for working the converters in compensating roles. The compensating role of converters is supported by the ESS capability, which complemented by the use of ultra-capacitor[30, 31]. The parameters of research interest are stability, availability through the use of ESS as reported in [31, 32]. The potential results will be showing active and reactive power with and without energy storage system (ESS) and ultra-capacitor using the proposed control strategy.

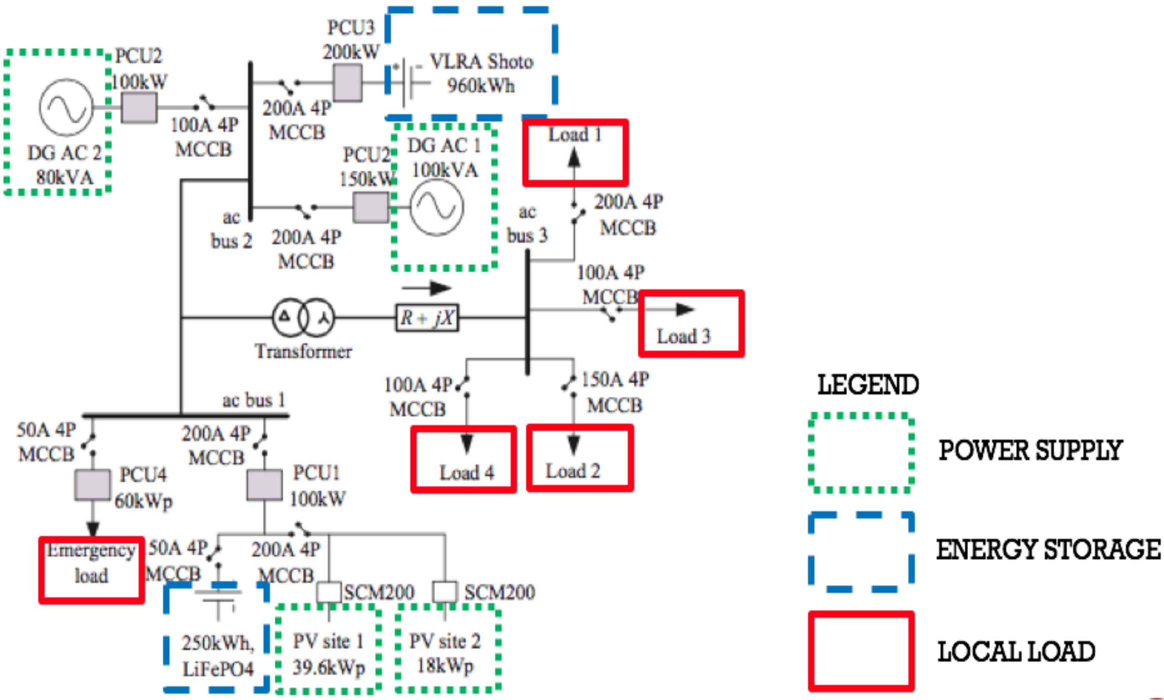



Fig. 2 Partial schematic diagram based on Fig. 1 [24]

## 4. Research Objectives

The research question open is what control strategy can be proposed by presenting a review of the diverse RES integrated with ESS and national grid-supply. The specific objectives are as under:

1. To investigate Distributed Generation system of modular structured Renewable Energy Sources in an overall power generation capacity.
2. To propose a control strategy for enhancing the stability of DG voltage using Energy Storage System (ESS) in structured converters.
3. To validate the performance of the proposed control strategy in improving the stability of the micro-grid under abnormal system conditions.

## 5. Research Scope

The scope of this research is related to work shown enclosed within a dotted box as shown on Figure 1. It covers proposing a control strategy between the Renewable Energy System (RES), Energy Storage System (ESS) and the power converters. The control strategy is based on the algorithm of the IF-ELSE-THEN with looping strategy that will turn ON and OFF of the power converters. The parameters that will be identified will be in term of Voltage (V) and Ampere (A) of each of the individual power converter.

## 6. Research Philosophy

Renewable energy is an emerging trend in the form of micro-grid, consisting of a DC bus as a pool of stable supply. The power pool is supplied mainly from RESS as well as from GRID in hours of need. The stability of the bus is guaranteed by an associated Energy Storage System (ESSS Battery) satisfying sometimes, contrasting parameters. A controlling mechanism for turning ON/OFF the sources to the bus or to the load or to the grid or ESS will conceptualize the scope of this research.

## 7. Research Methodology

The research methodology steps are elaborated here in Figure 3.

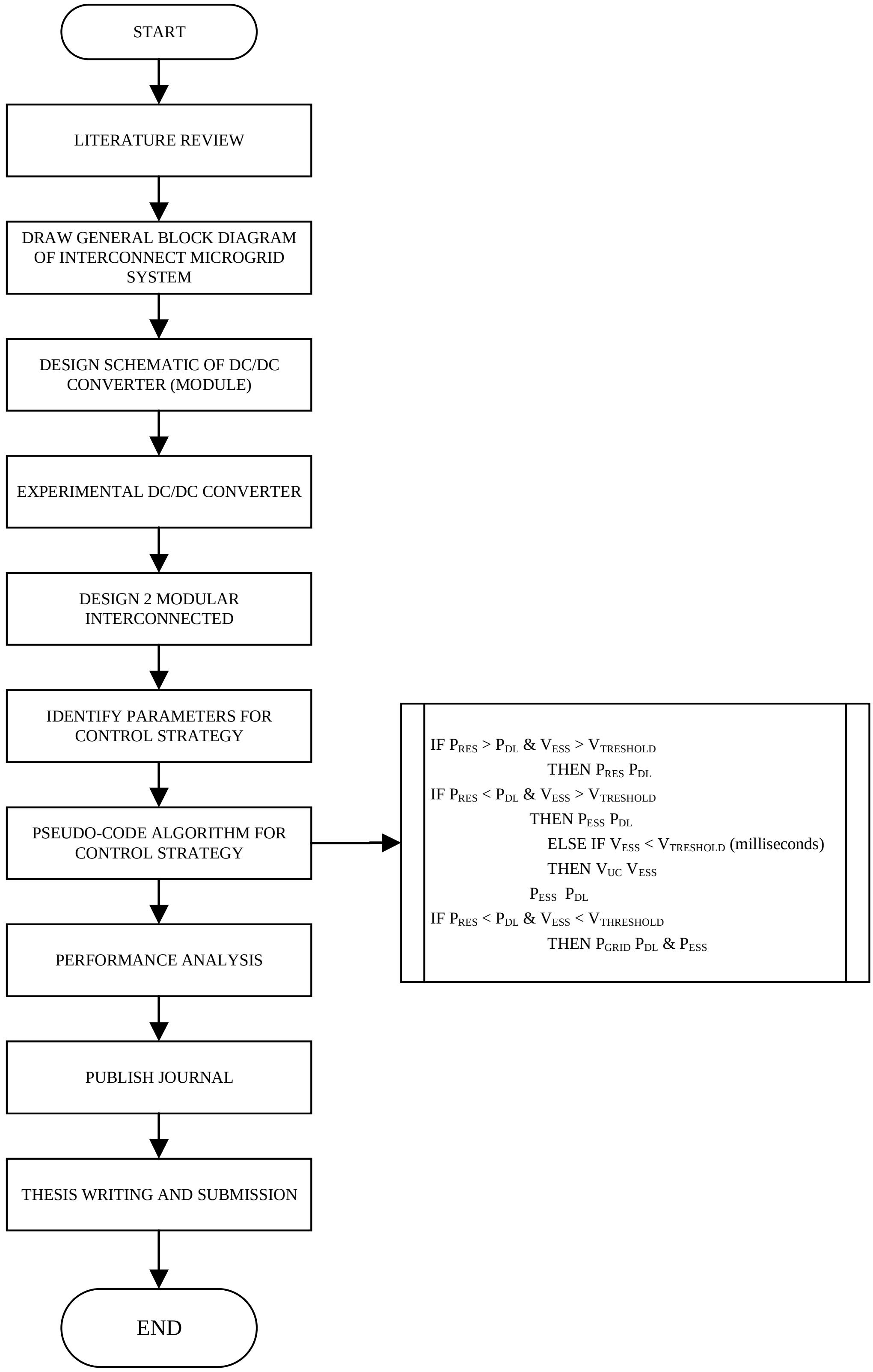



Figure 3 Research Methodology Pictorial View

## 8. Preliminary Results

In order to calculate and achieve the DC-DC Boost Converter power stage, some parameter will need to be considered such as input voltage range, the nominal output voltage, maximum output current and the Integrated Circuit of the specific designation.

The maximum switch current is calculated as follows

$$D = \frac{V_{IN(MIN)} \times \eta}{V_{OUT}} \tag{1}$$

$V_{IN(MIN)}$ = Minimum Input Voltage

$V_{OUT}$ = Desired Output Voltage

$\eta$ = Efficiency (estimated 80%)

For the inductor selection, it can be calculated as follows

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_s \times V_{OUt}} \tag{2}$$

$V_{IN}$ = typical input voltage

$V_{OUT}$ = desired output voltage

$f_s$ = minimum switching frequency

$\Delta I_L$ = estimated inductor ripple current

While it is based on the DC-DC Boost Converter, the circuit schematic is as in Figure 3 with the calculated parameters using equation (1) and (2). The schematic is simulated using NI Multisim.

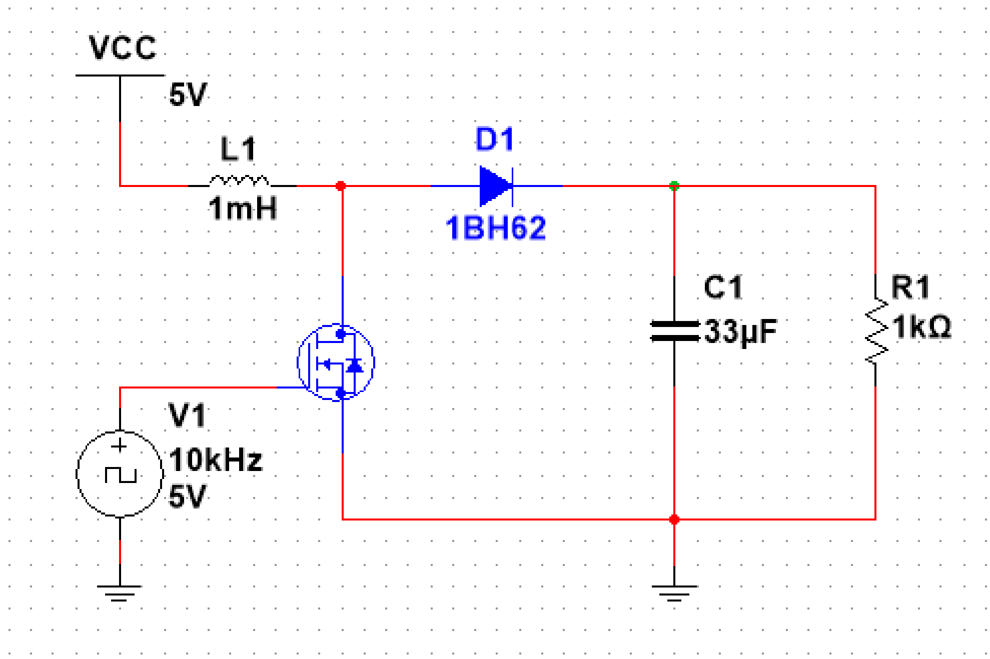



Figure 4 Schematic DC-DC Boost Converter

### 8.2 Simulation Results

The results obtain from the simulation as in Figure 4 is shown in Figure 5. The output is taken place at Input Voltage, Output Voltage(Inductor) and Output Voltage(Load).

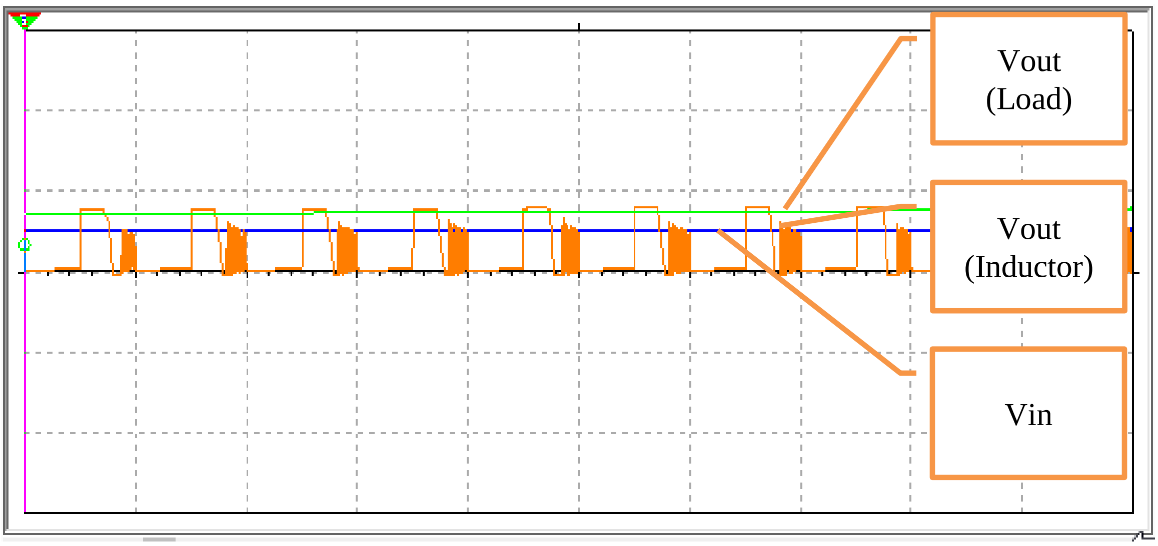
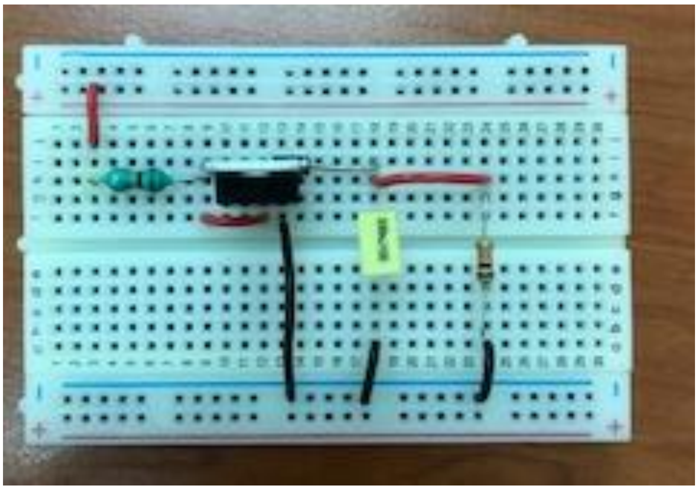



Figure 5 Output Waveform DC-DC Boost Converter

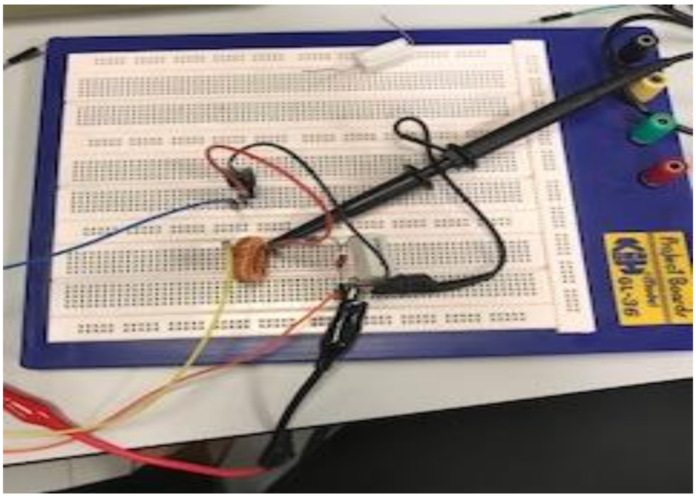
As in Figure 5, three waveforms showing the voltage output at load, Vout (Load), voltage output at inductor, Vout (Inductor), and input voltage, Vin.
This shows that the output voltage has been increased from the input voltage, as the function of the boost converter is to increase the input voltage.

### 8.3 Experimental Results

The experiment has been done by using the component as in simulation schematic. Below is the figure of the experiment that has been carried out.



(a)



(b)

Figure 6 Setup Components
(a) the layout components (b) the setup using oscilloscope

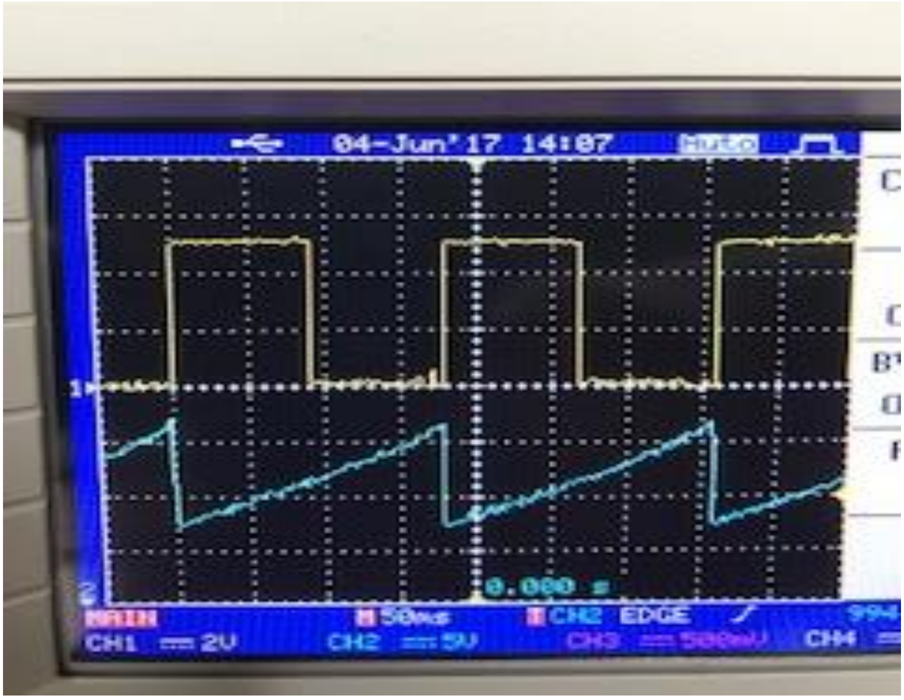



Figure 7 Oscilloscope Result

From the result obtained in Figure 7, the output voltage is varying while varying the duty cycle. Also, the inductor output voltage waveform also showing the varying ripple. The varying ripple inductor voltage as in Figure 7.

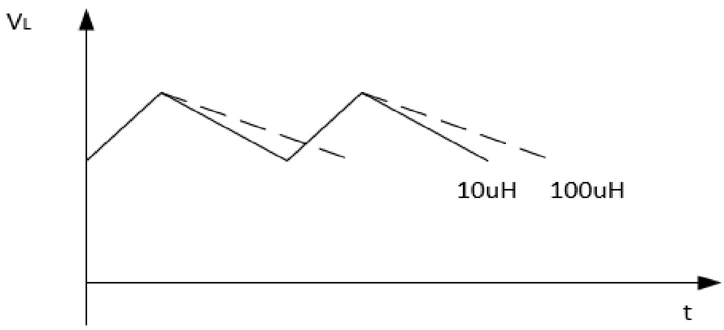



Figure 8 Inductor Voltages While Varying Inductor Value

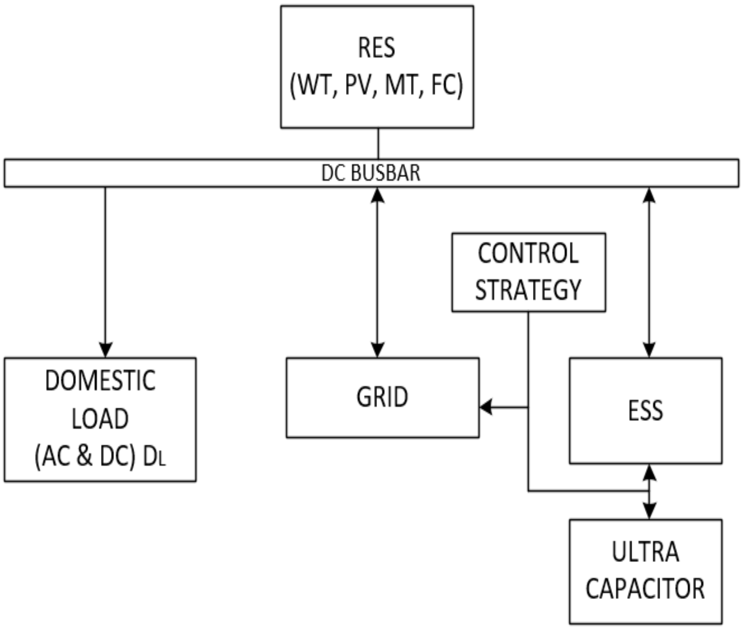



Figure 9 General Block Diagram IF-ELSE-THEN

**Controlling Logic for Power Flow**

IF $P_{RES} > P_{DL}$ & $V_{ESS} > V_{TRESHOLD}$

THEN $P_{RES} \rightarrow P_{DL}$

IF $P_{RES} < P_{DL}$ & $V_{ESS} > V_{TRESHOLD}$

THEN $P_{ESS} \rightarrow P_{DL}$

ELSE IF $V_{ESS} < V_{TRESHOLD}$ (milliseconds)

THEN $V_{UC} \rightarrow V_{ESS}$

$P_{ESS} \rightarrow P_{DL}$

IF $P_{RES} < P_{DL}$ & $V_{ESS} < V_{THRESHOLD}$

THEN $P_{GRID} \rightarrow P_{DL}$ & $P_{ESS}$

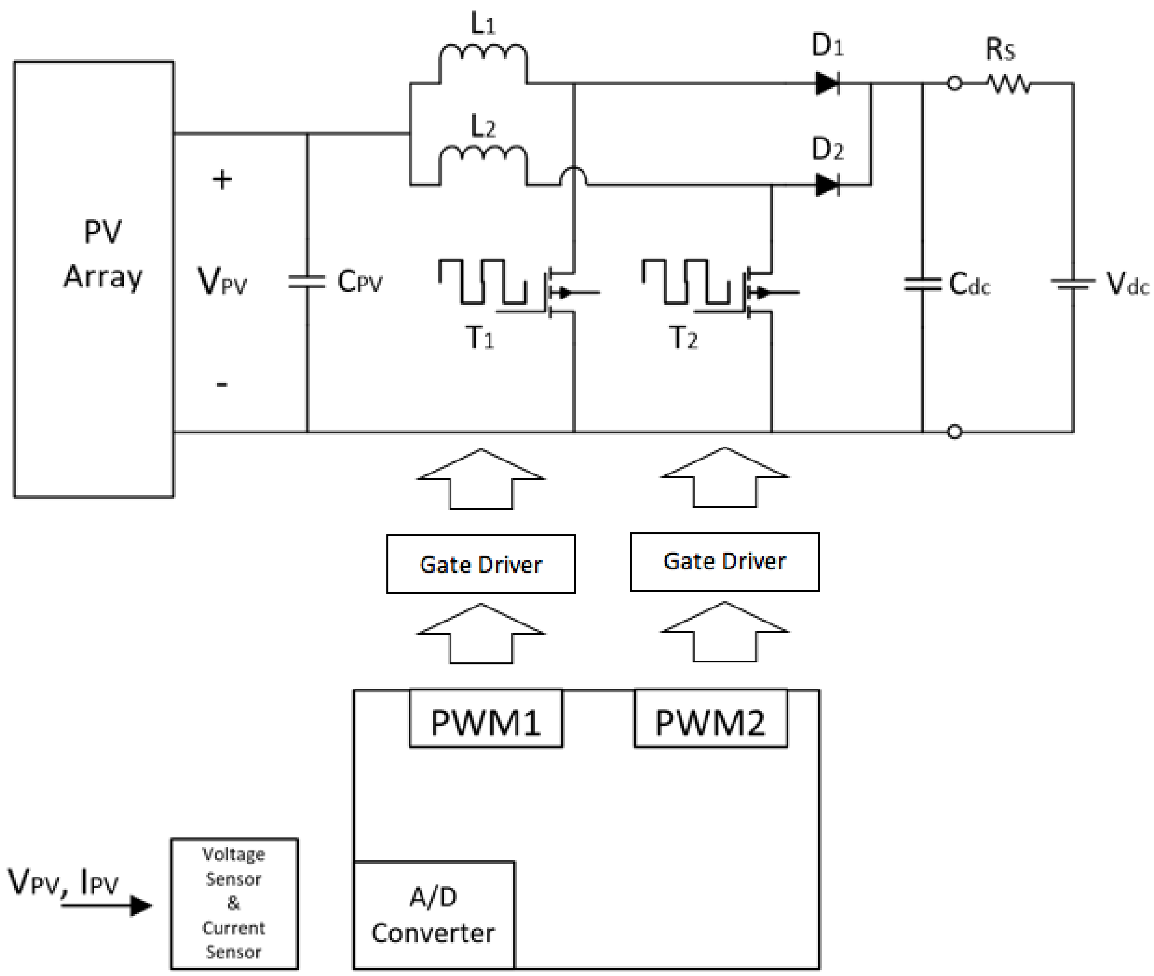



Fig. 10 Block Diagram of DC-DC Converter for PV Array

### 9. Conclusion

From the results obtained, it will give the determination of the Distributed Generation (DG) system of modular structured Renewable Energy Sources in an overall power generation capacity. The control strategy will be enhancing the stability of the DG in under either normal or abnormal system conditions.

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