Investigations on Sliding Mode Controlled Micro Grid System with Improved Time Domain Response

Bagam Srinivasarao, SVNL Lalitha, Yerra Sreenivasarao

***Abstract*: In recent times, micro grids are used along with the conventional generation systems. This work considers 'closed-loop-response' of P.I. and Slide- Mode- Controller (SMC)-based-micro-grid-systems'. The objective of the proposed-smart grid-system is to progress the dynamic-response of closed-loop micro Grid Systems (MGS) using suitable intelligent controller. SMC is proposed since it produces faster response to MGS with lesser spikes in output. Models were developed for P.I. and SMC based MGS. Simulation studies are performed and the outcome illustrates an improved dynamic performance by employing SMC. The analysis specifies that SMC-MGS has low settling-time and steady-state-error.**

***Index Terms*: Micro-Grid (MG) Distributed-Generation, Proportional integral (PI), Slide Mode Controller (SMC).**

I. INTRODUCTION

Micro grids have been usually considered as a structure block of upcoming smart grid [1], As a result there have been several actual islanded micro grid schemes build up for countryside in addition to remote areas [2–5]. Conventional PID-controller is authenticated in excess of 'I & PI' controllers optimized by Imperialist Competitive Algorithm(ICA) as demonstrated in [6, 7]. The cascade-blend of 'PI &PD-controllers' is implemented as internal & external-controller-loop within multi-area power-scheme.

The cascade PI-PD controller is certify like a superior controller compare with conventional PID controller in addition to the features of the controller are adjusted by Flower Pollination Algorithm (FPA) to boost the function of the controller in [8]. The degree of freedom (DOF) of the PID controller is increased in [9, 10] entitled as 2DOF PID controller to boost the features of the AGC in the combined-local-power-scheme reduced by "Cuckoo Search Algorithm(CSA) & Teaching Learning Based-Optimization(TLBO) algorithms" correspondingly.

Owing to the well-known utilize of Alternate Current (AC) electricity in the majority manufacturing, profit-making and housing purposes, the up to date writing on this subject primarily paying attention on AC micro grids [11]–[14]. Varying the voltages is necessary to make sure appropriate operation of coupled loads [15]–[16], while current division avoids overstressing the units.

Sliding mode control (SMC) recommends insensitivity in opposition to parametric suspicions in addition to exterior instabilities [17–19]. The grid-coupled inverter adjusted through the unchanging switching frequency SMC is introduced. A high-quality steady-state response can be attained, except babble and reduced transience be present [20,21]. "Proportional Load Sharing and Stability of DC Micro grid with Distributed Architecture Using SM Controller" is developed the Sliding Mode Control. Each resource in a DC micro grid contains a PE converter. The controllers like PI, PID, in addition to lead-lag be employed to manage the PE converters in favor of the load division difficulty in DC micro grids [22-24].

Other controllers need a linearized form within scheme, it creates complicated on behalf of them to show good power sharing recital in addition to constancy in every service circumstances So, an SM controller is alternatively proposed in which makes certain constancy in the entire working circumstances. Consequently, with in the article, an SM controller method is projected on behalf of relative load distribution plus constancy of DC micro grids.

Additionally, various controllers consist of error with together of the time derivatives with the fundamental of the error in the sliding plane to alleviate the scheme. With in condition, the sliding plane be able to be signify as a 2nd categorize deferential equation intended for which broad mathematical study is necessary to assurance scheme stability. An additional surface is mentioned for the enhancement in the steady-state error as well as settling time, which comprises voltage error with square of the capacitor current of the scheme. In the manuscript, an SM controller is designed to achieve energy dispersion and dynamic stability of DC micro-networks.

The sliding surface is chosen to guarantee load-sharing and exact voltage direction. Along these lines, it is shaped utilizing the bus-voltage blunder, current mistake, and vital of the bus-voltage blunder. Along these lines, the SM controller be able to recognize with limit the voltage and current mistakes. Further, the necessary activity is incorporated to lessen the consistent state voltage mistake.

The Function of Sliding Mode Controller Analysis is appeared in Fig 1. The majority of the controllers comprise fault of one or numerous-states of the structure in the sliding-surface (e.g., inductor-current addition to the capacitor-voltage).

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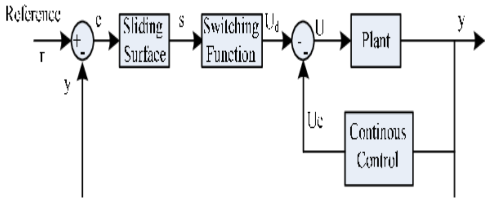

Figure--1 Block-Diagram of SMC (Slide–Mode-Controller).

Herein, the sliding-surface can be symbolized as a second-order differential-equation for which wide numerical study is needed to assurance system-steadiness. An additional surface is characterized for the recovery in the steady-state-error& settling-time, which comprises voltage-error.

II.PROBLEM FORMULATION

It is required to minimize the effect of fluctuations in wind speed or change from load on the output of MGS. It is also required to improve the reliability. The SMC-controller is suggested to improving time domain response. Line data and load data are specified. It is needed to model &simulate-MGS utilizing the 'blocks of Simulink'. It is required to regulate the voltage by using SMC controller. This effort recommends SMC in support of the control of MGS.

III.SYSTEM DESCRIPTION

Block illustration of PI–MGS scheme is exhibited in Fig.2. Loads receive power from conventional and wind sources. "Load-voltage" is sensed and it is evaluated among the "reference- voltage" to obtain the error. The inaccuracy is processed by means of PI controller. The output of PI controller be utilized to renew the pulse width of the boost converter of PV and FC schemes. Load-data & line-data of 'MGS' are specified in Table-1 and Table-2 correspondingly. The details of MGS scheme are as follows: Photo voltaic source Rated at 1.4 MW , voltage rating is 3.0KV ;Fuel cell Rated at 3.0KW , voltage rating is 500V ; Battery Rated at 3.5KW , voltage rating is 500V ; Diesel generator rated at 3.0 MW, voltage rating is 3KV ; Transformer Rated at 3.0 MVA; Wind generator Rated at 6.0MW , voltage rating is 3.3KV.

TABLE- I. LOAD DATA

Bus No	Real Power (Mw)	Reactive Power(Mvar)
BUS-2	0.469	0.287
BUS-3	0.471	0.293
BUS-4	0.514	0.315

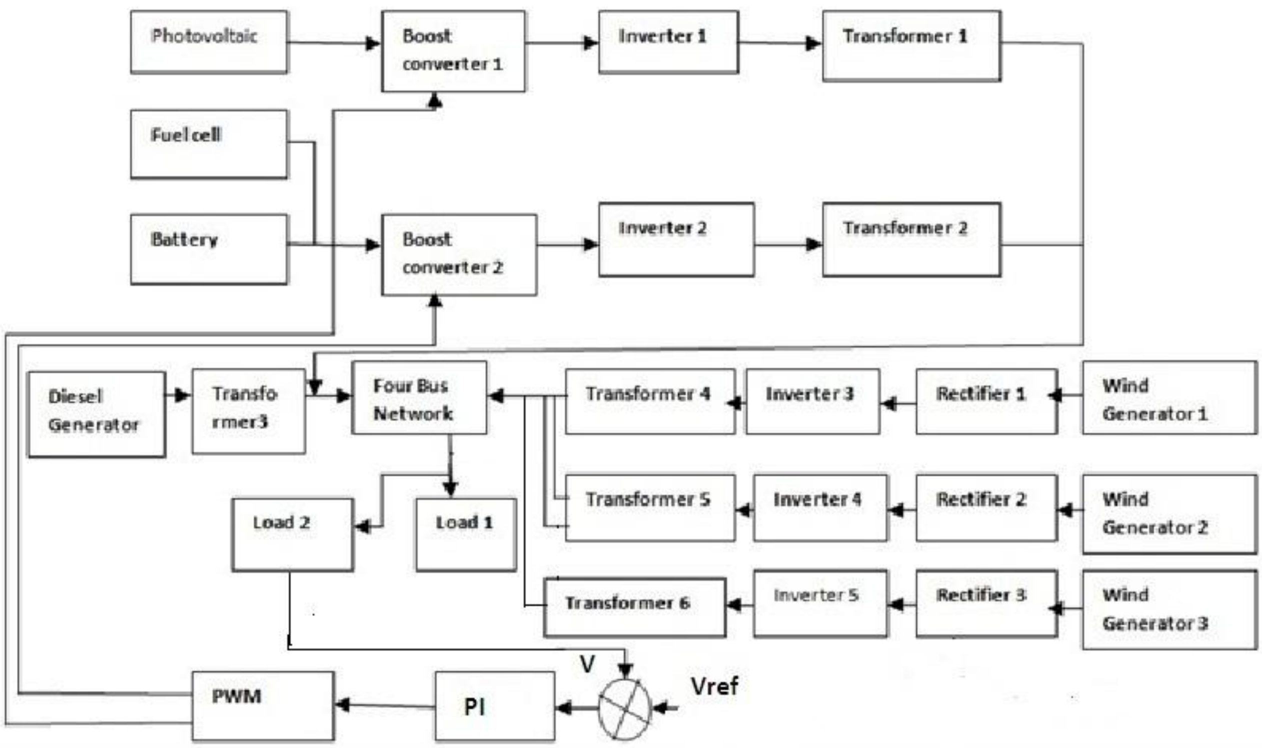

Fig.2 Block diagram of PI–MGS

Block diagram of planned SMC -MGS is revealed in Fig.3. Loads receive power from conventional and wind sources. "Load-voltage" is sensed and it is evaluated among the "reference- voltage" to obtain the voltage- error. The error be processed by means of SMC controller. The output of SMC be utilized to revise the pulse width of the boost converter between P.V and F.C schemes.

TABLE- II, LINE DATA

	Line Impedance	
	RESISTANCE	***Inductance***
BUS 1-2	0.001Ω	33mH
BUS 2-3	0.05Ω	30mH
BUS 3-4	0.01Ω	20mH

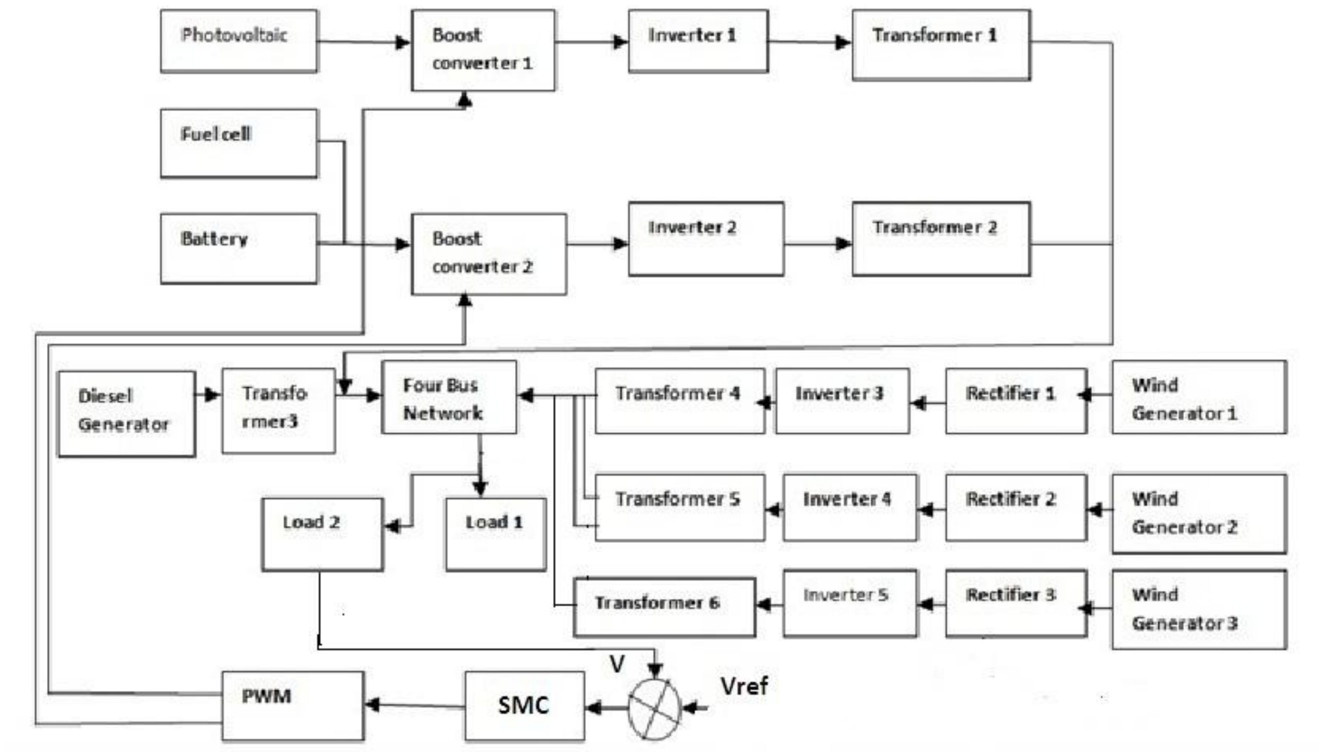

Fig.3 Block diagram of proposed SMC Controlled–MGS

IV.ANALYSIS

The formulas in favor of wind-turbine are as detailed below.

Power (P) = 0.6 x R_e x n x a x v^3

Rotations (rpm) = V x T x 60 / (6.28 x s)

R_e = Rotor Efficiency

n = Driven machinery efficiency

a = Area sweep by rotor (m^2)

v = velocity of wind (m/s)

T = Tip Speed Ratio ,

s = Rotor radius,

Rotor effectiveness be able to go away like elevated as R_e = 0.48, however R_e = 0.4 be frequently utilized into this style computations.

The width of the blade be moreover called the blade chord. A superior method in favor of figure this is:

Blade Chord (n) = 5.6 x R^2 / (m x C x f x T),

R = Tip radius in m

f = Point of computation radius

m = number of blades,

C = Lift coefficient,

TSR = Tip Speed Ratio.

Energy = 0.5 x Mass x Velocity^2

In this the mass be mentioned in kg also velocity as m/s, in addition to the power is specified in joules. Air contain acknowledged density (approximately 1.23 kg/m^3).

V.SIMULATION RESULTS

The Circuit-diagram of the closed-loop micro-grid-scheme by means of PI controller Vref=6300 Volts is appeared in Fig-5. Load-voltage be sensed in addition to it is match up to among the reference-voltage in the direction of get the voltage-error. The error is specified toward a PI controller. Out-put of PI be applied to a pulse-generator. Four-bus network,wind-generator P.I controller and pulse generator are shown as sub-schemes.

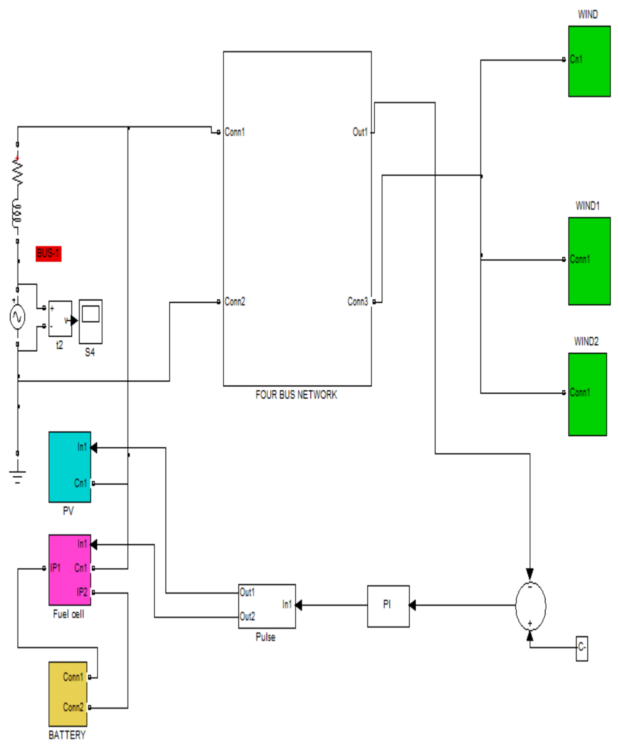

Figure 4 Circuit illustration of the closed loop with PI controller (Vref=6300V)

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The voltage at bus-6 in closed-loop micro-grid-scheme through PI controller is appeared into Fig 5 and its value is $0.8*10^4$V.

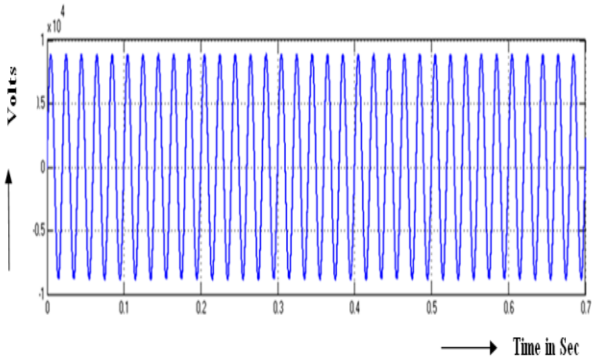

Figure 5 Voltage at bus-4

The RMS--votage at bus-4 in closed-loop micro-grid-scheme with PI controller be displayed into Fig 6 as well as its value be 6249 V.

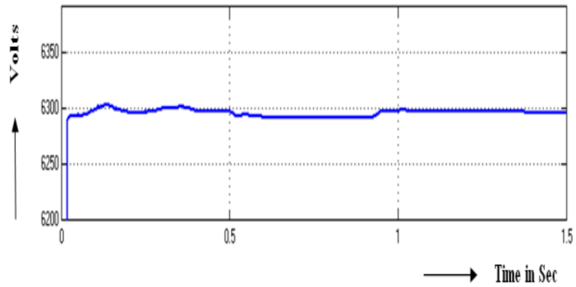

Figure 6 RMS voltage at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme by PI controller be appeared in Fig 7 and its value is $4.4*10^5$Watts.

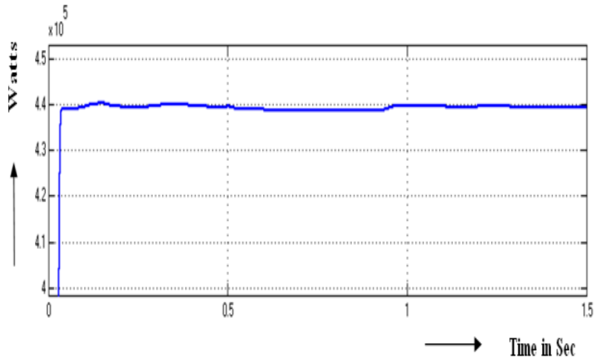

Figure 7 Real power at bus-4

The reactive-power at bus 4 in closed-loop micro-grid-scheme with PI controller be appeared in Fig 8 and its value be $8.410*10^5$VAR.

The Circuit-diagram of the closed-loop micro-grid-scheme by means of PI controller Vref=6350 Volts be appeared into Fig-9. Four-bus network,wind-generator P.I controller and pulse—generator are shown as sub-systems.

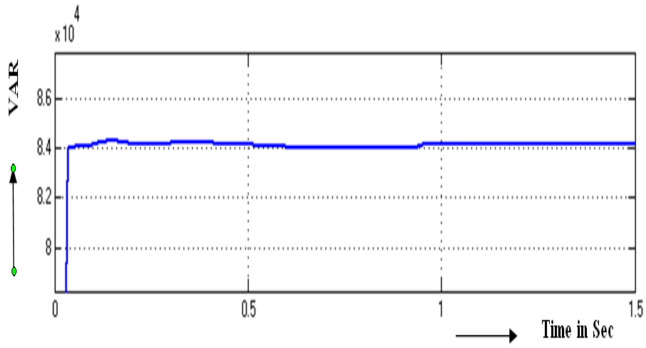

Figure 8 Reactive power at bus-4

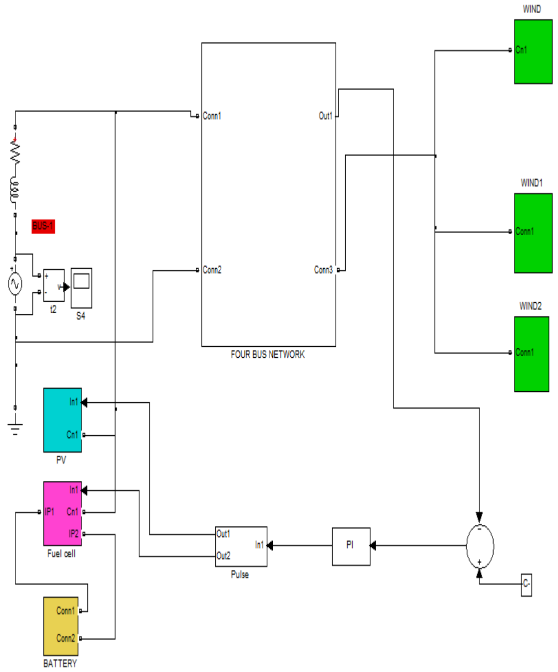

Figure 9 Circuit illustration of the closed loop among PI controller(Vref=6350V)

The voltage at bus-4 in closed-loop micro-grid-system with PI controller be appeared into Fig 10 and its value be $0.8*10^4$Volts.

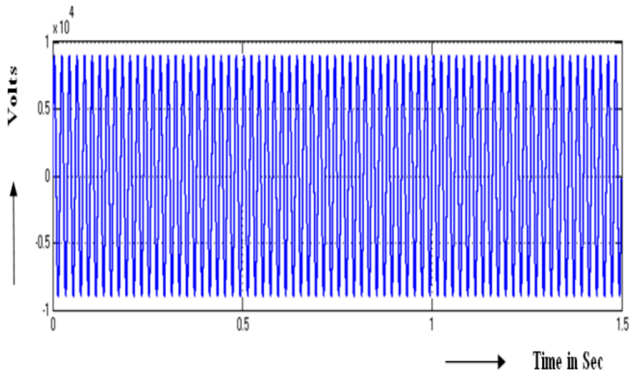

Figure 10 Voltage at bus-4

The RMS--votage at bus-4 in closed-loop micro-grid-scheme by means of PI controller be appeared in Fig 11 and its value is 6250 Volts.

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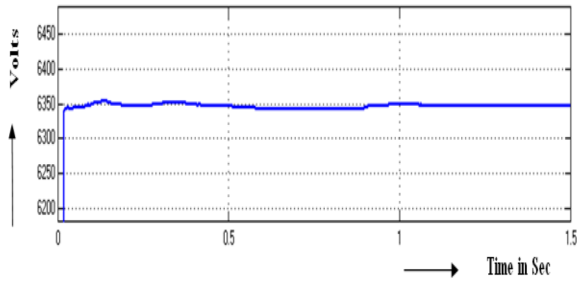

Figure 11 RMS voltage at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme with PI controller is appeared into Fig 12 and its value is $4.43*10^5$Watts.

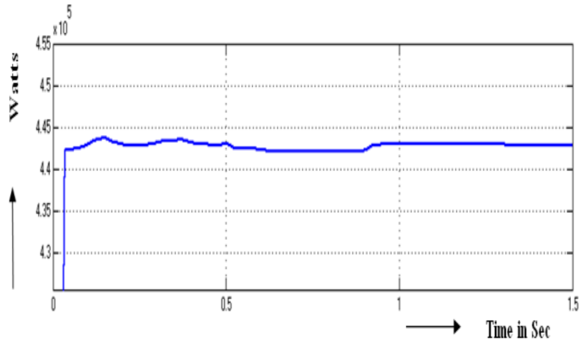

Figure 12 Real power at bus-4

The reactive-power at bus 4 in closed-loop micro-grid-scheme by means of PI controller be appeared into Fig 13 and its value is $8.490*10^4$VAR.

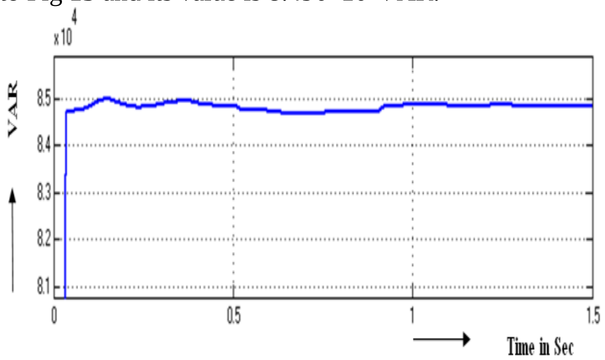

Figure 13 Reactive power at bus-4

The Circuit-illustration of the closed-loop micro-grid-scheme by means of PI controller Vref=6400 Volts be appeared in Fig-14. Four -bus network,wind-generator P.I controller and pulse generator are shown as sub-systems.

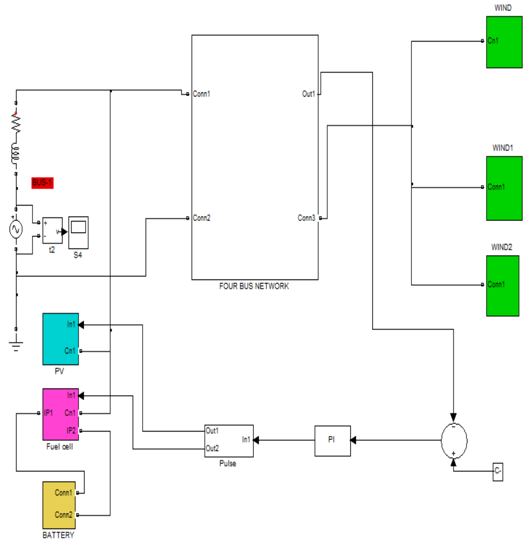

Figure 14 Circuit illustration of the closed loop through PI controller(Vref=6400v)

The voltage at bus-4 in closed-loop micro-grid-scheme with PI controller is appeared in Fig 15 and its value is $0.8*10^4$Volts.

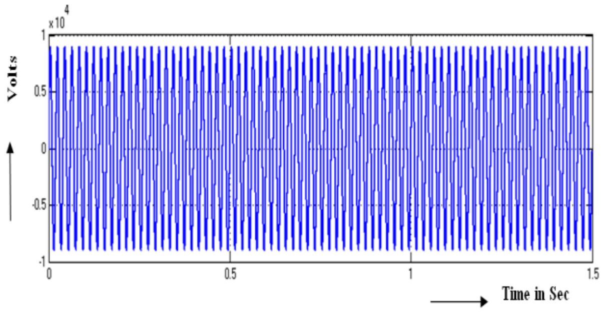

Figure 15 Voltage at bus-4

The RMS--votage at bus-4 in closed-loop micro-grid-scheme with PI controller is appeared in Fig 16 and its value is 6250 Volts.

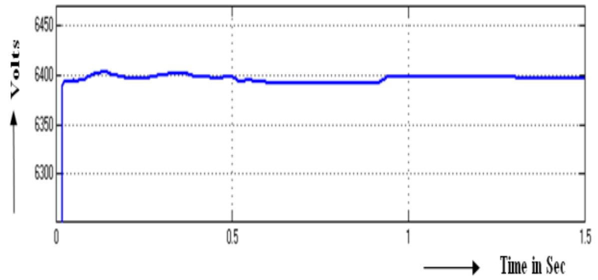

Figure 16 RMS voltages at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme with PI controller is appeared in Fig 17 and its value is $4.43*10^5$Watts.

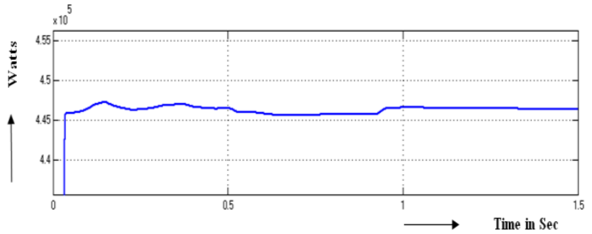

Figure 17 Real power at bus-4

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The reactive-power at bus 4 in closed-loop micro-grid-scheme with PI controller is appeared in Fig 18 and its value is $8.4*10^4$VAR.

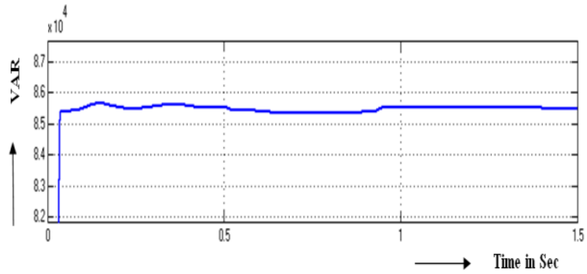

Figure 18 Reactive power at bus-4

The Circuit-diagram of the closed-loop micro-grid-scheme with Slide mode controller Vref=6300 Volts is appeared in Fig-19. The PI controller in the above network is replaced by a SM controller. Four -bus network, wind-generator SM controller and pulse—generator are shown as sub-systems.

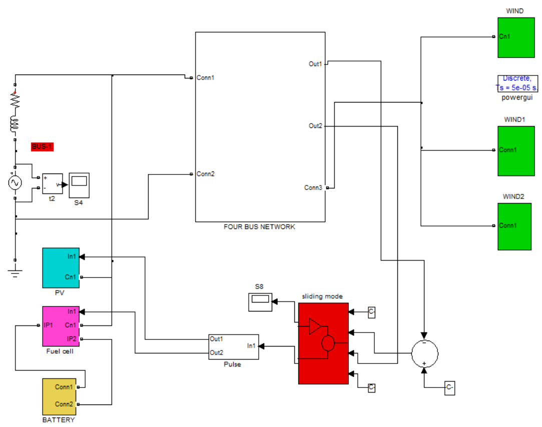

Figure 19 Circuit diagram of the closed loop with SM controller(Vref=6300V)

The voltage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 20 and its value is $0.8*10^4$Volts.

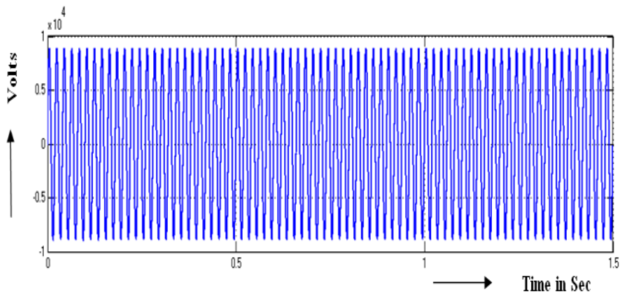

Figure 20 Voltage at bus-4

The RMS--votage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 21 and its value is 6308 Volts.

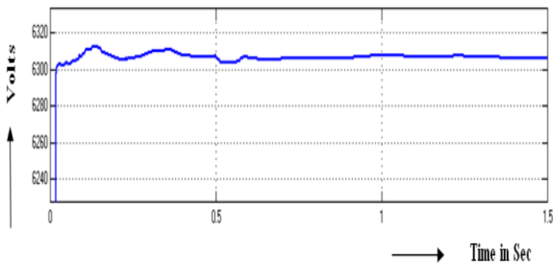

Figure 21 RMS voltage at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 22 and its value is $4.4*10^5$Watts.

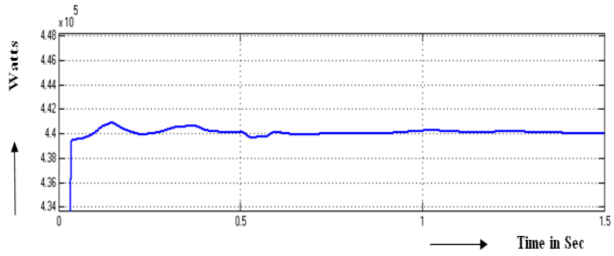

Figure 22 Real powers at bus-4

The reactive-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 23 and its value is $8.43*10^4$VAR.

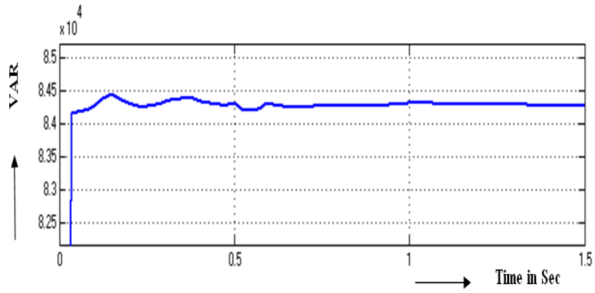

Figure 23 Reactive power at bus-4

The Circuit-diagram of the closed-loop micro-grid-scheme with Slide mode controller Vref=6350 Volts is appeared in Fig-24. Four -bus network, wind-generator SM controller and pulse—generator are shown as sub-schemes.

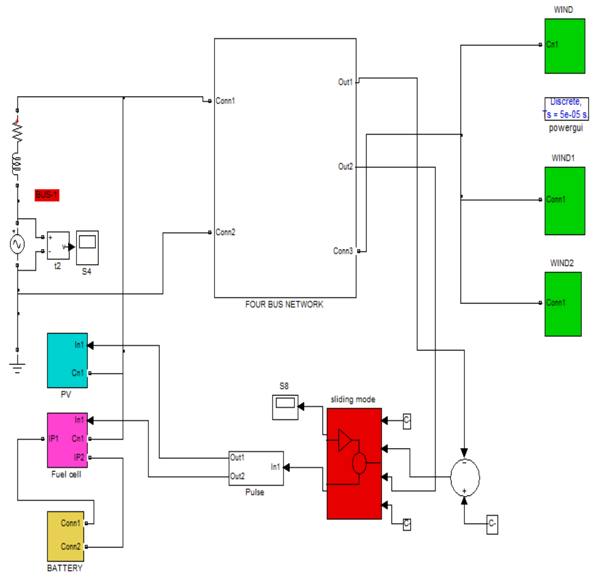

Figure 24 Circuit diagram of the closed loop with SM controller(Vref=6350V)

The voltage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 25 and its value is $0.8*10^4$Volts.

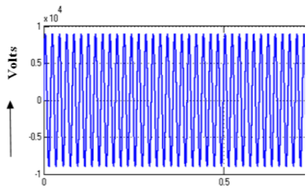

Figure 25 Voltage at bus-4

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The RMS--votage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 26 and its value is 6348 Volts.

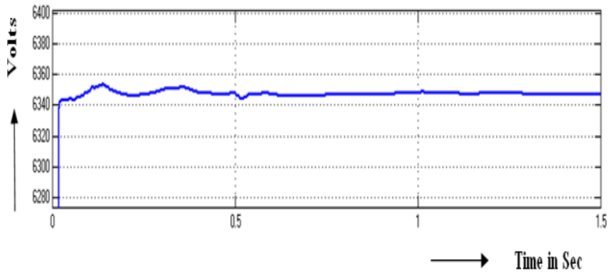

Figure 26 RMS voltage at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 27 and its value is $4.445*10^5$Watts.

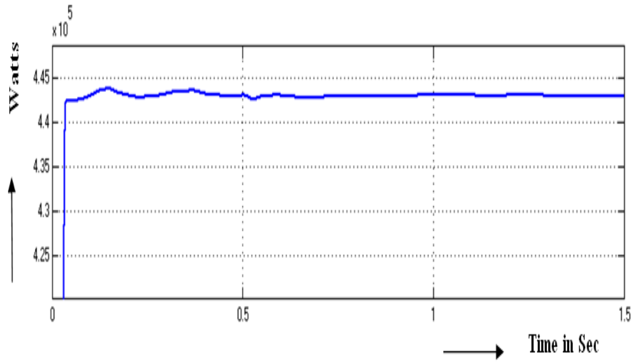

Figure 27 Real power at bus-4

The reactive-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 28 and its value is $8.88*10^4$ VAR.

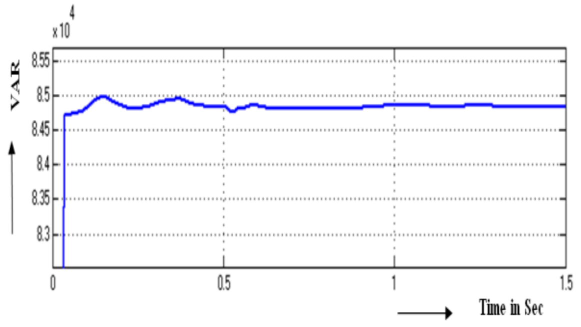

Figure 28 Reactive power at bus-4

The Circuit-diagram of the closed-loop micro-grid-scheme with Slide mode controller Vref=6400 Volts is appeared in Fig-29. Four -bus network, wind-generator SM controller and pulse generator are shown as sub-schemes.

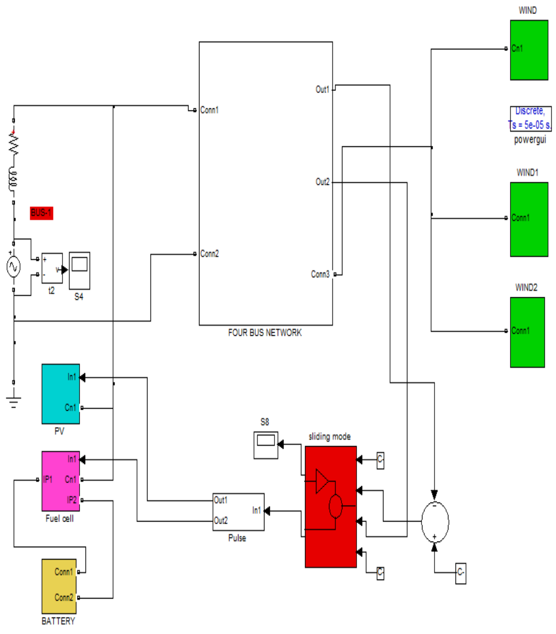

Figure 29 Circuit diagram of the closed loop with SM controller(Vref=6400V)

The voltage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 30 and its value is $0.8*10^4$Volts.

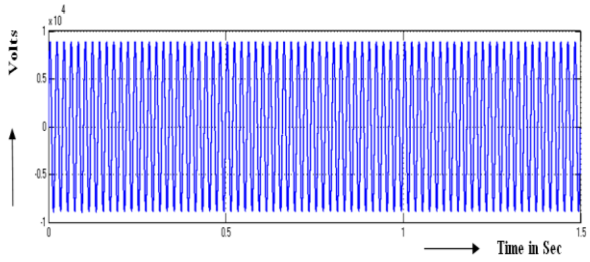

Figure 30 Voltage at bus-4

The RMS--votage at bus-4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 31 and its value is 6400 Volts.

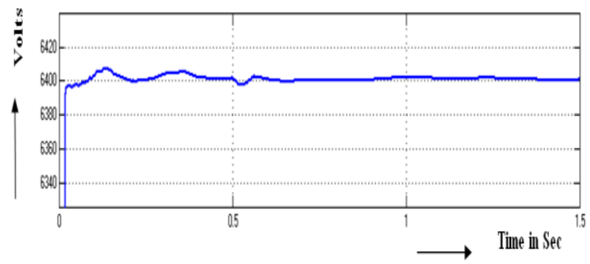

Figure 31 RMS voltage at bus-4

The real-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 32 and its value is $4.4695*10^5$Watts.

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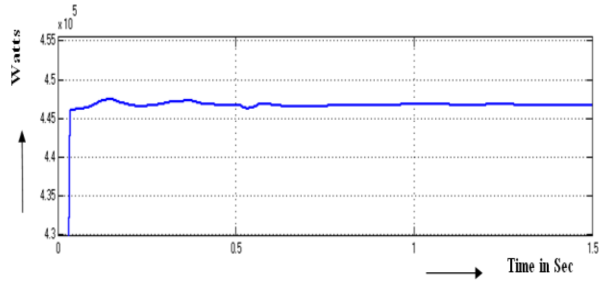

Figure 32 Real power at bus-4

The reactive-power at bus 4 in closed-loop micro-grid-scheme with SM controller is appeared in Fig 33 and its value is 4.4695*10^4VAR.

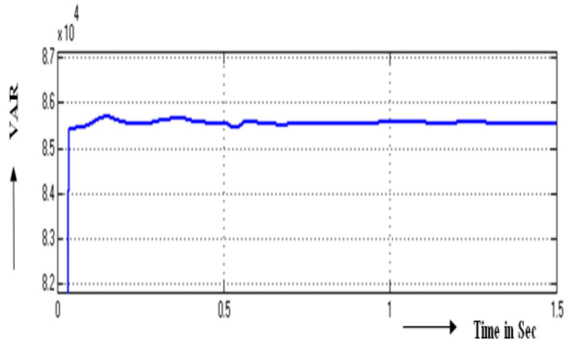

Figure 33 Reactive power at bus-4

The distinction of time-domain values Vref=6300 volts with PI and SMC is given into Table-3. The 'rise-time' be diminished as of 0.54 sec towards 0.51 sec; the 'peak-time' be reduced as of 0.86 sec towards 0.55sec; the 'Settling-time' be reduced as of 0.93 sec, 0.57 sec and steady-state-error be condensed as of 4.3 volts towards 1.6 volts by replacing PI-controller with SM-controller.

TABLE III. COMPARISON OF TIME DOMAIN PARAMETERS WITH VREF = 6300 V

Types of controller	T_r Sec	T_p Sec	T_s Sec	E_{ss} Volts
PI	0.54	0.86	0.93	4.3
SMC	0.51	0.55	0.57	1.6

Comparison of time-domain-parameters Vref = 6300 volts with PI and SMC is given in Table-3. The 'rise-time' is diminished as of 0.52 sec towards 0.50 sec; the 'peak-time' is reduced as of 0.82 sec towards 0.51 sec; the 'Settling-time' is condensed as of 0.90 sec, 0.53 sec and steady-state-error is condensed as of 3.8 volts towards 1.1 volts by replacing PI-controller with SM-controller.

TABLE IV. COMPARISON OF TIME DOMAIN PARAMETERS (VREF=6350V)

Controller name	T_r Sec	T_p Sec	T_s Sec	E_{ss} Volts
PI	0.52	0.82	0.90	3.8
SMC	0.50	0.51	0.53	1.1

The Comparison of time-domain-parameters Vref = 6350 volts with PI and SMC is given in Table-4. The 'rise-time' be weaken as of 0.53 sec towards 0.50 sec; the 'peak-time' be reduced as of 0.84 sec towards 0.52 sec; the 'Settling-time' be condensed as of 0.92 sec, 0.54 sec in addition to steady-state-error be reduced as of 4.0 volts towards 1.3 volts by replacing PI-controller with SM-controller.

TABLE V. COMPARISON OF TIME DOMAIN PARAMETERS (VREF=6400V)

Types of controller	T_r Sec	T_p Sec	T_s Sec	E_{ss} Volts
PI	0.53	0.84	0.92	4.0
SMC	0.50	0.52	0.54	1.3

VI. EXPERIMENTAL RESULTS

The Hardware image for MGS is appeared in Fig-17. The hardware contains the 'rectifier-board', 'inverter-board', 'control-board', 'transformer' &'load-board'. The 'input-voltage' is appeared in Fig-18. 'Switching-pulses for M1& M3inverter' are outlined in Fig-19. The 'Output-voltage of Rectifier' be appeared into Fig-20. The 'Output-voltage of inverter' be appeared into Fig-21. 'Complete-hardware-diagram for the MGS' is delineated in Figure-22. The hardware consists of 'inverter-board', 'rectifier-board' & 'control-board'. 'List of hardware components used' is given in Table-7. The hardware consists of PIC16F84A, diodesIN4007, driver2110 and regulators 7812 & 7805.

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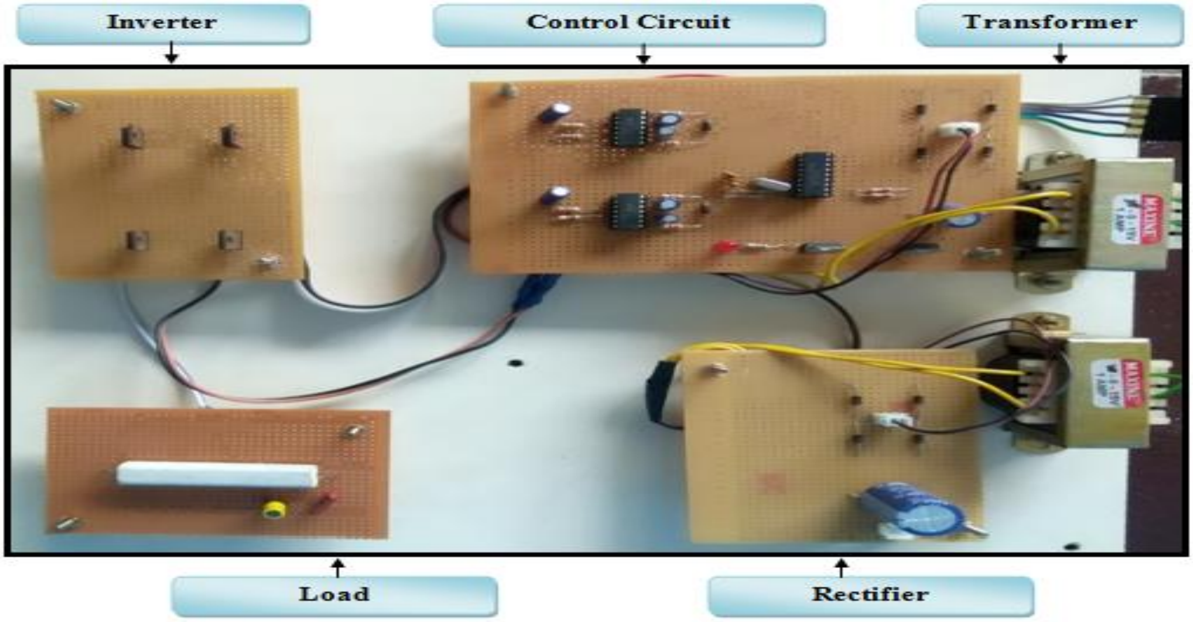
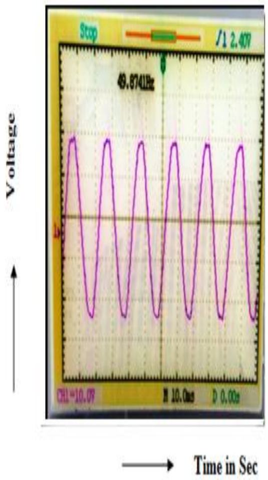


Fig 17 Hardware snap shot of MGS



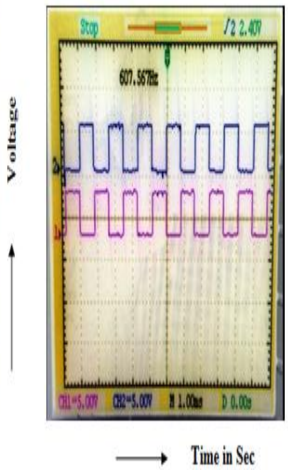
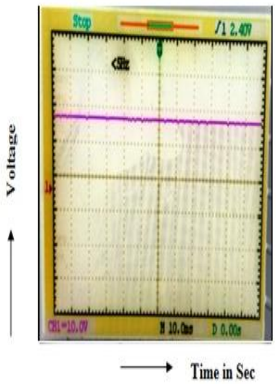


Fig-18 Input-voltage of WG Fig-19 switching pulses for M1 & M3



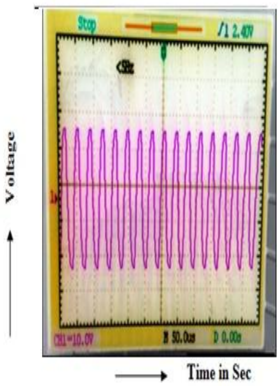


Fig-20 Output-voltage of Rectifier Fig 21 Output voltage of inverter

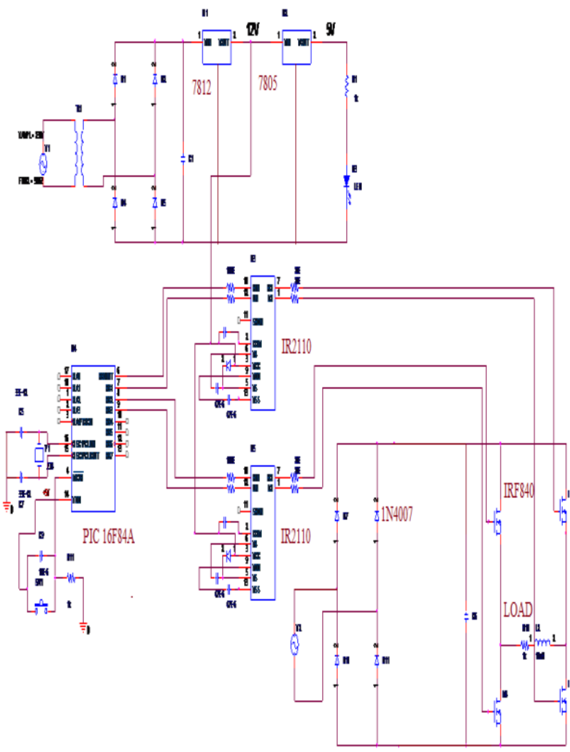


Fig-22 Complete-hardware-diagram of MGS

Table-7. List of hardware components

NO	Name	Rating	Type
1	Capacitor	1000E-03	Electrolytic
2	Capacitor	4.70E-05	Electrolytic
3	Capacitor	3.30E-11	disc
4	Capacitor	2.20E-03	Electrolytic
5	Diode	1000V ,3A	PN Junction

6	Inductance	10uH	ferrite coil
7	MOSFET (IR840)	600V,8A	N-channel
8	Resistor	1k	Quarter watts
9	Resistor	100E	
10	Resistor	22E	
11	Regulator	12V	L7812/TO3
12	Regulator	5V	L7805/TO220
13	IC	IR2110	Opto-coupler
14	P-Ic controller	P-IC16F84A	RISC
15	PCB	V105	General

VII. CONCLUSION

MG Schemes controlled through PI and SMC are modeled as well as simulated using simulink. The simulation results from closed loop Scheme among PI as well as SMC for various-reference-values are presented. Simulation and numerical results have been presented with supporting comparisons. The values of steady state error and settling time are minimum with a reference value of 6350V. Therefore the response from SMC-MGS is superior to PI-MGS. The advantages of proposed scheme are high reliability and improved response. The effectiveness of MGS scheme has been improved using SMC- SMC. The disadvantage of proposed MGS scheme is the increased cost due to wind generators.

The investigations into PI and SMC based MGS schemes reveals that SMC based scheme shows better performance than P.I. controlled MGS scheme. It can be seen that the time response from SMC is superior to the P.I controlled MGS.

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