Photovoltaic Integrated Electric Vehicles Charging stations for Isolated locations

Peeyush Pant[1]*
Dept. of Electrical and Electronics Engineering
Bhagwan Parshuram Instt. Of Tech
Delhi, India
pantpeeyush@gmail.com

Gaurav Sharma[2]
Dept. of Electrical and Electronics Engineering
Bhagwan Parshuram Instt. Of Tech
Delhi, India
sharma.gaurav1x1@gmail.com

Hemant Kumar Rajput[2]
Dept. of Elect and Electronics Engineering
Bhagwan Parshuram Instt. Of Tech
Delhi, India
hemantrajput@bpitindia.com

***Abstract*— Future mobility plans of global countries focus on replacement of IC engines operated mechanism by electrically powered systems. It aims to reduce carbon footprints, improve fuel efficiency and make vehicle systems smarter. A typical electric vehicle is an integration of battery banks, charge management systems, electric motors, power electronic converters, and control mechanisms. The battery bank maintains the supply of energy for the operation of the motor which in turn drives the transmission system of the vehicle. The vehicle battery discharges during operation and needs to be charged. In urban areas where grid supply is available, battery charging is done at utility grid connected charging stations. The interfacing charging converter causes peak demand and power quality issues of the utility grid. Charging of electric vehicles in roadside locations where grid is not supplied is a rather challenging issue. Electricity generation using freely and abundantly available renewable energy sources to charge e-vehicle batteries appears to be cost-effective. In this paper, photovoltaic integrated electric vehicle charging station is proposed for isolated locations. The system can supply clean, free, long-lasting pollution-free battery charging options to isolated locations. A dynamic model of 30kW system has been developed integrating solar PV, battery storage, charge and load controller, local load of charging station. The proposed system is simulated in Matlab/Power-System Blockset and the performance of the system during steady state and load varying conditions is evaluated by the obtained simulation results. The results validate the effectiveness of the proposed system and meet the charging requirements of electric vehicle in remote locations by solar photovoltaic.**

Keywords— Electric mobility, solar PV, vehicle charger, renewable energy, PWM inverter

****Author for Correspondence E-mail: pantpeyush@gmail.com, Tel:011-27572900***

I. INTRODUCTION

Serious concerns for climate change, eco-friendly lifestyles, air pollution and energy security have forced researchers to develop new schemes for energy conversion and security. Energy extraction using conventionally available energy sources like coal, petrol, diesel and gas is on the decline as these sources are facing problems like limited reserves, expensive and leaving carbon footprint on the atmosphere. Global electricity consumption is increasing with the adoption of electric mobility and transportation sector which otherwise use petrol/gas powered IC-engines. The adoption of e-mobility will provide an energy efficient and eco-friendly solution in the transportation sector, and encourage researchers to develop new schemes that offer promising scope to replace existing vehicle systems. Electric vehicles (EVs) integrate an electric motor, controller, battery bank with a power management system and battery charging centres are connected to the utility grid with converters. Withdrawal of power from grid supply can stress the distribution system or reduce its power quality. Furthermore, in places where grid supply is not available, the adoption of electric mobility is a challenging issue as the battery takes a long time to charge and the vehicle may have limited driving range. The lack of availability in convenient charging infrastructure leads to the deployment of diesel-generator, charge battery swapping, which increases charge overhead and unreliable battery charging. The investigation is due to develop a system that provides a cost-effective, reliable, uninterrupted and efficient system for charging electric vehicles in an environment-friendly manner. Global policies on energy seem to be relatively effective in deploying renewable energy sources for EVs battery charging. Among available renewable energy resources solar PV is well established to provide clean, free, long-lasting and pollution-free electricity with low carbon emissions. Electric vehicle charging by using renewable energy are being investigated

This paper proposes photovoltaic integrated electric vehicle charging station to supply clean, free, long-lasting pollution-free battery charging options where grid supply is not available. The proposed system is also suitable for public charging of electric vehicle in locations such as public parking lots, on-street parking, charging plazas, petrol pumps, highways, metro stations, municipal authority, and public areas. A dynamic model of 30kW system has been developed by integrating solar PV, battery storage, charge/ load controller, and charging station utilities. The proposed system is simulated in Matlab/Power-System Blockset and the performance of the system is evaluated by simulation results.

II. LITERATURE REVIEW

Energy extraction using conventional resources such as coal, petrol, diesel, and gas are facing a decline due to being costly, leaving a carbon footprint and depreciating reserves. The adoption of electric vehicles in the mobility sector has promising prospects in the future. E-vehicle battery technologies are to be investigated for their size and cost optimization, efficient charging, renewable energy sources (RES) integration, and demand-side management (DSM). Investigations are made by the researchers to cater growing need of charging points for electric vehicle [1]-[5]. Lam et al. [1] formulated investigation to address the placement of electric vehicle charging station and proposed scheme to minimize the total construction cost of charging station. Mehar et al. [2] and Hsieh et al.[3] proposed scheme to optimize location for charging stations of electric vehicles. Investigations on relay requirement and traffic assignment of electric vehicles alternate fuel mixed-integration had been proposed [4]-[5]. Investigations on data-driven optimization-based approach for siting and sizing of electric taxi charging stations was proposed by Yang et al. [6]. Zheng et.al [7] proposed a scheme on traffic Equilibrium and developing electric vehicles charging facility locations. Dait et al. [8] proposed method to address fast charging station placement with elastic demand. Investigations were proposed on charging station with battery integration for reducing electric vehicles charging queue and cost by using renewable energy curtailment recovery. Investigations were made to address the issues based on fast charging and simultaneous charging station location-routing problem [10]-[11]. In recent years investigations on electric vehicles charging stations in microgrid pattern by using renewable energy are under researchers scope [12]-[16]. It is observed that reported schemes on charging stations are focused on optimization, designing and analysis of the system. Utilizing renewable resources and forming isolated microgrid for EV charging applications has not been attempted. Investigation on solar photovoltaic fed battery charging station in remote location requires investigations to relieve power grid erection and generate electricity in cost effective manner.

In this paper solar PV fed isolated charging station for electric vehicles (EV) has been proposed. The scheme generates electricity without leaving carbon footprints. Battery charging in dynamic manner is proposed. The station is fed through Solar PV system. The aim of investigation is to reduce both system cost and carbon emissions. The scheme also relieves the requirements of power grid erection in isolated locations for e-vehicles charging. Analysis and simulation model of proposed PV fed EV Charging system has been developed for dynamic simulations. The system has been simulated in Matlab Power system Blockset and performance of system is simulated by using simulation results validate the fact that the proposed system caters demand side energy requirements for e-charging in remote locations.

III. SYSTEM CONFIGURATION

Battery specifications of electric vehicle is important criterion of changing station. The kWh capacities and voltage levels of batteries used in typical EVs are depicted in Table 1.

Table 1

Type of Vehicle	Battery Capacity	Battery Voltage
E-2Wheeler (2W)	1.2-3.3 kWh	48-72V
E-3 Wheeler (passenger/ goods) (3W)	3.6-8 kWh	48-60V
E-cars(1st generation)	21 kWh	72V
E-cars(2nd generation)	30-80 kWh	350-500V

For effective charging/discharging the power supplied to battery is to be maintained at rated voltage and current levels. Normal charging range of an electric vehicle ranges up to 22kW whereas, high power charging can be up to 200kW. Typical power levels of electric vehicle charging stations are shown in Table 2.

Table 2

	Power level	Current type	Compatible EV segments
Normal power charging	$P \leq 7kW$	AC & DC	E-2Ws, e-3Ws, e-cars, other LCVs (up to 1 ton)
	$7kW < P \leq 22kW$	AC & DC	
High power charging	$22kW < P \leq 50kW$	DC	E-cars, LCVs and MCVs (1-6 tons)
	$50kW < P < 200kW$	DC	

The block diagram of the proposed electric vehicles charging station is shown in Fig.1. The photovoltaic (PV) array supplies power (P_{PV}) to the dc-boost converter. The PV array output voltage (V_o)in conjunction with a battery bank presents regulated voltage. The battery bank is integrated by battery management system(BMS) and maintains bidirectional power control. The BMS also regulates optimal charging/ discharging of batteries and caters 75V dc charging ports of electric vehicle station. Energy balance during light loading at charging ports is maintained by evacuating excess power by chopper based load-controller at array output. A three-phase inverter has been integrated with the output dc bus of boost converter. To support battery charging of 2^{nd} generation cars typically at 350-500V a small boost converter has been integrated at dc bus of inverter. The filtered output voltage of inverter supports ac charging ports of EV and also caters local ac loads presented by the charging station. The proposed system is flexible to cater battery charging requirements for both ac and dc chargers in isolated charging system and for locations where grid supply is not available.

IV. SYSTEM MODELLING

The proposed system for EV charging in isolated locations includes PV arrays, battery storage, boost converter, voltage source converter, load controller and control mechanism. The mathematical model of the system has been realized in the following sub sections of this paper.

A. *Solar PV Module*

Network of solar cell presents solar module which are integrated to maintains requisite voltage at array output. The mathematical model of a solar cell is based on simplified irradiance model. The output power depends on irradiance, area of panel and photoelectric conversion efficiency. The power output (P_{PV}) of solar array is given as.

$$P_{PV} = G_T A\eta \qquad (1)$$

Where G_T is forecasted irradiance, A is the area of solar panels, and η is efficiency of solar power conversion.

B. *Boost Converter*

The source voltage (V_s) is regulated by duty cycle (D>0) and output (V_o) is obtained as

$$V_0 = V_s/(1-D) \qquad (2)$$

$$D = 0.15 \text{ (Considering } V_s = 75\text{V and } V_o = 500\text{V)} \qquad (3)$$

the inductor and capacitor is estimated by

$$L = V_s D / (\Delta i_L . f) \qquad (4)$$

$$C = D/ ((R(\Delta V_0 / V_0)f) \qquad (5)$$

where V_s, Δi_L,f, ΔV_0 and R are the input voltage, inductor ripple current, switching frequency, capacitor ripple voltage and output impedance of boost converter respectively.

C. *Voltage Source Converter (VSC)*

The VSC supplies caters both local loads presented by charging station and ac charging port of electric vehicle The transacted power is governed by the following equation

$$P - jQ = 3\frac{v_a e_a}{x_f}\sin\alpha - j3\left(\frac{v_a e_a}{x_f}\cos\alpha - \frac{v_a{}^2}{x_f}\right) \qquad (6)$$

The real- power (*P*) depends on the load angle (α), and the reactive power flow (*Q*) depends on the voltages v_a and e_a.. Gating pulses are accordingly supplied with the control algorithm for IGBTs switching to maintain regulated voltage across the load.

The volt-current equation of inverter output is given as

$$v_a = R_{f.}i_{ca} + L_f pi_{ca} + e_a - R_f i_{cb} - L_f pi_{cb} \qquad (7)$$

$$v_b = R_{f.}i_{cb} + L_f pi_{cb} + e_b - R_f i_{cc} - L_f pi_{cc} \quad (8)$$

$$i_{ca} + i_{cb} + i_{cc} = 0 \qquad (9)$$

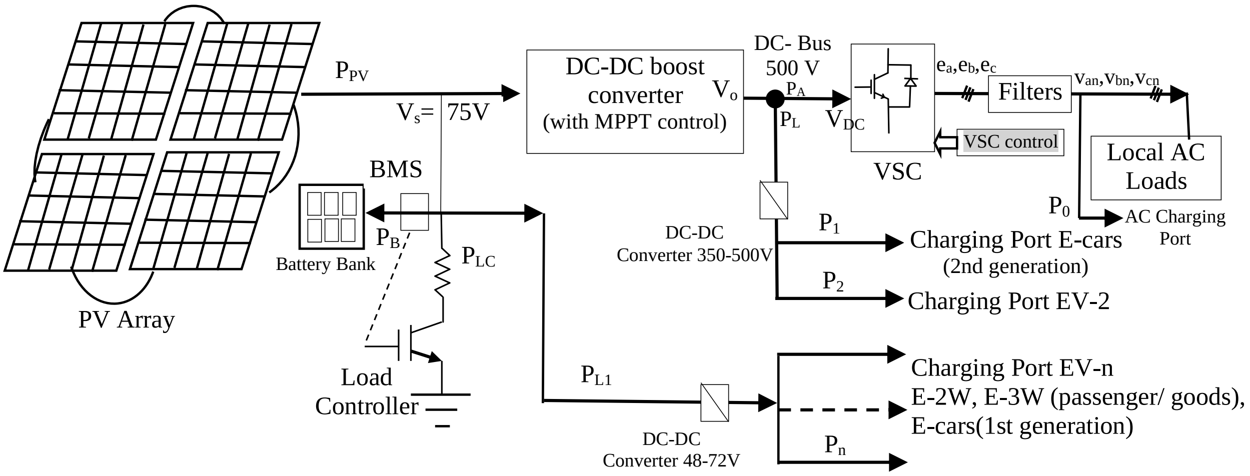

Fig.1. Block diagram of the proposed system for charging the electric vehicles (E-2W, E-3W,E-cars)

$$v_b = R_f.i_{cb} + L_f.pi_{cb} + e_b + R_f.i_{ca} + L_f.pi_{ca} + R_f i_{cb} + L_f.pi_{cb} \qquad (10)$$

Rearranging eqn. (9) and eqn. (10) result as,

$$L_f.pi_{ca} - L_f.pi_{cb} = v_a - e_a - R_f.i_{ca} + R_f.i_{cb} \qquad (11)$$

$$L_f.pi_{ca}+2L_f.pi_{cb}=v_b-e_b-R_f.i_{ca}-2R_f.i_{cb} \qquad (12)$$

VSC current derivatives are estimated as

$$pi_{ca}=\{(v_b-e_b)+2(v_a-e_a)-3R_f i_{ca}\}/3.L_f \qquad (13)$$

$$pi_{cb}=\{(v_b-e_b)-2(v_a-e_a)-3R_f i_{ca}\}/3.L_f \qquad (14)$$

D. Regulation of dc bus (V_{DC}) voltage

The dc-bus voltage is regulated by duty cycle of boost converter. The converter draws power from the solar-PV source. For satisfactory power transaction the voltage at dc bus of inverter must be greater than twice the peak of the phase voltage at the ac terminals of VSC. Minimum dc bus voltage required for proper operation of VSC is

$$V_{DC}=\left(2\sqrt{2}/\sqrt{3}\right)m.V_a \qquad (15)$$

For '*m*' is 0.9 and line voltage (V_a) is 380V dc bus voltage (V_{DC}) is obtained as 500V for VSC operation in self-supported mode.

The sensed dc bus voltage (V_{DC}) is passed through low pass filter (LPF) and sampled *k* times over a period *T*.

$$V_{DC}(k)=\frac{1}{k}\sum_{l=n-k+1}^{l=k}V_{DC}(k) \qquad (16)$$

The filtered dc voltage is compared with reference voltage and the error (e_{vDC}) is estimated

$$e_{V_{DC}}(k)=V_{DC}*(k)-V_{DC}(k) \qquad (17)$$

The error is processed through a controller (PI) and requisite current drawn from the source is determined. This corresponds to real-power to be drawn from the source to maintain dc bus voltage ($V*_{DC}$) constant

$$I_{ddc}(k)=K_{pd}\{e_{V_{DC}}(k)+e_{V_{DC}}(k-1)\}+K_{id}e_{V_{DC}}(k) \qquad (18)$$

E. Load Controller

A chopper-based load controller implemented in parallel to battery source evacuates the power when vehicles are not available at the charging point. The power supplied from the source comprises the power transacted in dc-bus and power drawl for charging the battery. The power balance equations during steady state is expressed as

$$P_C=P_{PV}-P_{LC} \qquad (19)$$

Where, P_c is the net active power output transacted for EV charging. Current drawn by the capacitor I_{DC} for maintaining voltage V_{DC} is related by power accumulated in the capacitor (C) by

$$P_C=V_{DC}I_{DC} \qquad (20)$$

Implies

$$P_C=V_{DC}C\frac{dV_{DC}}{dt}=\frac{C}{2}.2.V_{DC}\frac{dV_{DC}}{dt} \qquad (21)$$

$$=\frac{C}{2}\frac{dV_{DC}{}^2}{dt} \qquad (22)$$

Rearranging eqn. (19) and integrating both sides

$$V_{DC}{}^2=\frac{2}{C}\int P_C dt \qquad (23)$$

$$V_{DC}=\sqrt{\frac{2}{C}\int P_C dt} \qquad (24)$$

Substituting P_c in eqn. (21), the dc bus voltage (V_{DC}) can be expressed in terms of generator output power (P_g), and the power dissipated in the load controller.

$$V_{DC} = \sqrt{\frac{2}{c}\int (P_c - P_{LC})dt} \tag{25}$$

In terms of duty cycle, the power (P_{LC}) dissipated in bleeder resistance (R_b) is given as-

$$P_{LC} = \frac{(\delta V_{DC})^2}{R_b} \tag{26}$$

F. *Load Presented by eVehicle*

Electrical loads presented by a typical e-vehicle charger presents constant-power loading (CPL). The response of such load is analyzed through piecewise linearizing the nonlinear supply perturbations. The loads intermittency due to charging perturbations in a proposed weak system often causes voltage sag ΔV(say), which may result in current displacement of 'ΔI' from 'I_1', thus, disturbing the equivalent resistance perceived at common coupling. The resistance is expressed as-

$$R_{e1} = \frac{P_{load}}{(I_1 + \Delta I)^2} \approx \frac{P_{load} / I_1^{\,2}}{1 + \frac{2\Delta I}{I_1}} \tag{27}$$

From Taylor's series expansion and approximation in equivalent resistance in eqn. (27) becomes

$$R_{e1} = \frac{P}{I_1^{\,2}}\left(1 - \frac{2\Delta I}{I_1}\right) = \frac{P}{I_1^{\,2}} - \frac{P}{I_1^{\,2}}.2.\frac{\Delta I}{I_1} = R_e - 2.R_1\frac{\Delta I}{I_1} \tag{28}$$

It is observed in eqn. (27) that fall in resistance (R_e) provokes escalation in current drawl and sag in voltage. Such loading produces cascading effect in line voltage and may lead voltage collapse. Dynamic compensation of power may prevent further fall in voltage and prevents the voltage collapse.

V. CONTROL ALGORTHIMS

Block diagram of the proposed control scheme is depicted in Fig. 2. The scheme ensures to maintain energy balance by effectively regulating the power transaction via photovoltaic generation, battery storage, boost converter, local utility loads, inverter, and load controller operation. Solar PV arrays integrated with battery energy storage system ensures regulated supply voltage which otherwise fluctuates due to change in solar irradiance. The battery bank provides power topping and fulfills excess energy requirement of the system during transient overload conditions. A boost converter in maximum power point tracking (MPPT) control algorithm maintains regulated voltage across the dc-link by requisite duty cycle control. Charging of electric vehicles on both ac and dc ports presents electrical load on the system. Real power is estimated and the controller assures energy balance during both in light load and overload condition. During light load power matching at the point of common coupling (PCC) is maintained by optimal charge transfer to the battery storage by real power evacuation through chopper-based load controller. The local utility loads such as lighting, pumping, heating, and ac charging for EV is catered through VSC. The scheme ensures to maintain regulated voltage and frequency at ac side and cater charging loads of e-vehicles in effective manner.

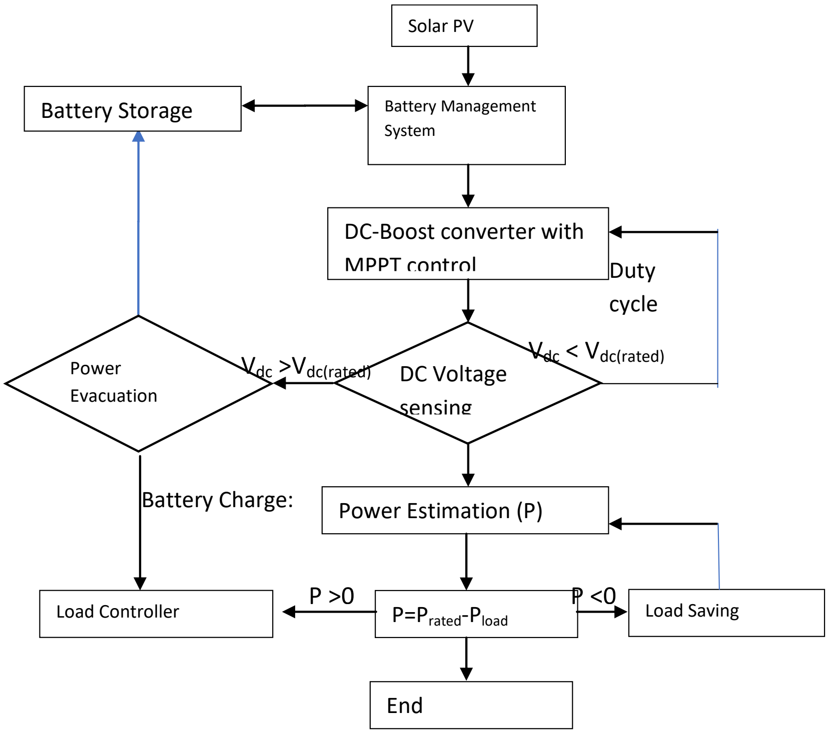

Fig.2. Block diagram of the proposed control scheme

VI. MATLAB SIMULATIONS

To evaluate the performance of proposed solar-PV fed isolated charging station the system is simulated in Matlab environment (Refer Fig.3.) Mathematical blocks of system components such as solar-PV array, battery storage, boost converter, local utility loads, inverter, and load controller are realized for simulation studies and requisite system model has been developed. The simulation parameters of the considered e-charging station are kept close to the actual enabling correct assessment of both control parameters and power circuit interfacing system. Electrical loads perceived in a typical e-vehicles charging system are presented as constant power loads (25kW). A band of 0.1A is considered for realizing carrier less PWM signals for inverter control with switching frequency of 10kHz. The attained results presented in the next section of the paper clearly demonstrates that the proposed control scheme offers effective voltage and frequency regulation to cater local loads and presents effective energy balance of the proposed system.

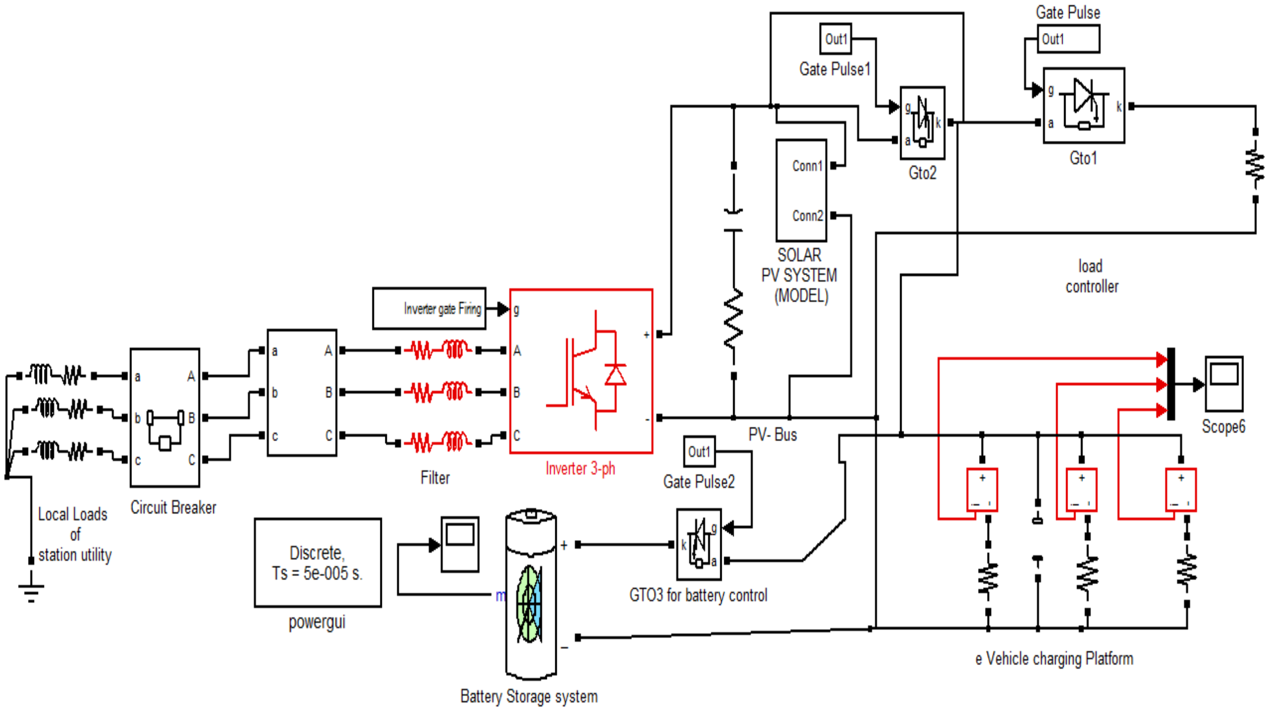

Fig.3. Block diagram of the proposed solar-PV fed isolated charging station in Matlab_PsBlockset

VII. Performance Of The System

Performance of the proposed e-vehicle charging station in isolated of operation has been evaluated using Matlab®/Simulink. The parameters of system components under investigation are kept close to the actual parameters. The attained results are shown in Fig.4. For the sake of clarity the results are arranged in two separate sections. One part deals with steady-state performance of the system and the other part dealt with the system performance during load perturbations. The performance of the proposed system has been discussed in the following sections.

A. Steady State Performance of the System

The steady state performance of the system has been studied when system caters rated load as charging of e-vehicles and local utility gadgets at PCC. The load further changes to light load even when vehicle is not present in charging station. The performance of the system is evaluated and the attained results are shown in Fig.4

1) Steady-State Performance of the System at Rated Load

Simulation based performance of the system when rated load is applied is shown in first section of Fig.4 during t=2.5s- 3.0s. The per phase line voltage at PCC of inverter and current drawn from the source is depicted in Fig.4 (f, g). It may be clearly observed line to line terminal voltage is balanced and regulated. Also, the current drawn by local load is balanced and supply frequency is well regulated.

Fig.4(a-e), section t=2.5 to 3.0s. shows the voltage at dc-bus when system caters rated load. The system performance during steady-state operation depicting EV charging current, current transacted to/fro battery storage and load controller current. It may be clearly observed in Fig. 4(a) that dc-bus voltage is well regulated. It is also observed in Fig. 9(b) that current drawl is well regulated under limits. Also, as observed in Fig. 4(c) that current drawn by charging of each e-vehicle is steady and well regulated. The current drawn by the load controller is near zero since the employed load is near to rated capacity and effective energy balance is maintained. However, fraction of real-power is compensated in diode rectifier losses. The system operated stably and presents effective operation during steady-state operation.

2) Steady-state performance of the system at light load (Local load removal)

Performance of the system during light load at PCC of IG shown Fig.4(a-g) during t=3.0s-6.0s. The plot depicts dc-bus voltage, current, e-vehicles charging currents, Battery current, load controller current, line voltage and line current at PCC respectively. The results are explained during load perturbation when local load is not presented from t=3.0s-4.0s and battery bank optimally charged from t=4.0s-5.0s. During section t=5.0s-6.0s electric vehicle is not available at charging station. The dynamic performance of the system under local load changes has been presented in following sections.

a) Performance of the system with local load blackout

It may be observed in Fig.4 (f,g) that PCC voltages collapses and no current drawl has been observed by load utility. A glitch in current is observed in Fig.4(d) and current drawl by battery storage seems reducing. However, in this slot it is observed in Fig 4 (a-c) that dc-bus voltage, load current and e-vehicle charging current is well regulated.

b) Performance of the System with step loading by e-charging

As observed in Fig.4 (t=4.0s) that step loading implemented by e-vehicle charging. A glitch is observed in dc-bus current drawl shown in Fig.4(b). The increased current drawl is supported by battery storage leading it to discharging mode. However, in this slot it is observed in Fig. 4(a) that dc-bus voltage is well regulated presenting effectiveness of the proposed system.

c) Performance of the system during unavailability of vehicles at station

Complete load removal is observed in Fig.4 (t=5.0s) when both local load and e-vehicle charging are not presented at the station. During this condition drop in current drawl by e-vehicle is clearly shown in Fig.4 (b). Energy balance is maintained by dispensing real power to load controller and rise in current is shown in Fig 4(c). Effectiveness of the proposed system is presented by the fact that dc-voltage is well regulated under effective control.

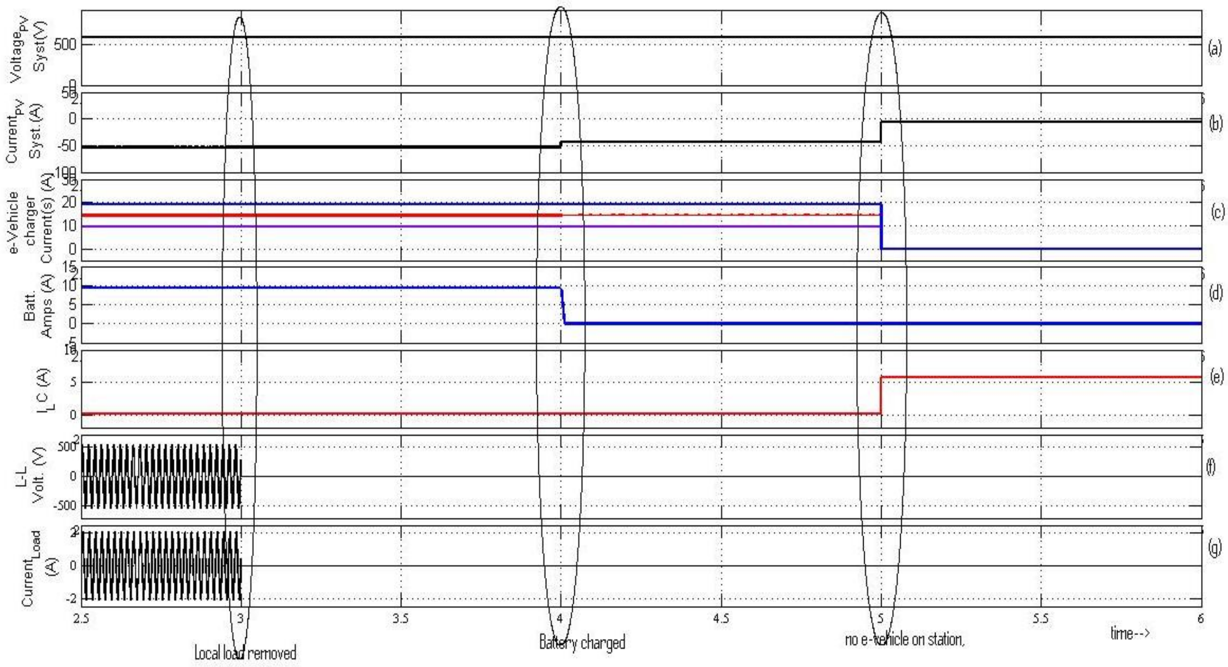

Fig.4. Performance of the proposed e-vehicle charging station in isolated of operation.

VIII. CONCLUSION

The performance of proposed generation system pertaining energy self-sufficient e-vehicle charging station in isolated mode integrated with solar photovoltaic has been successfully demonstrated under load perturbations. The system caters e-vehicle charging, lighting, heating, and local pumps of isolated charging station. For local utility appliances regulated voltage and frequency has been attained at PCC. The operation of load controller presents rated power drawl from the source effectively. The proposed scheme is simple, fast acting and prevents complex hardware circuits. It is also successfully demonstrated that the system remains under synchronism even under extreme load perturbations. For e-vehicle charging in rural locations the scheme presents easy and effective.

IX. FURTHER SCOPES

In this paper, an isolated charging station is proposed to charge e-vehicle. This provides feasibility to charge the vehicle where grid supply is not available and reduces grid erection burden. The scheme also increases the EVs utilization at remote locations by using the PV. In this paper regulated voltage of dc bus is connected to cater loads. The scheme provides further scope to erect grid and power exchange power during the absence or reduced sunlight. Constant current method has scope to charge battery of electric vehicle during load/ source perturbations.

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