Dynamic Simulation of an Isolated Solar Powered Charging Facility for 20 Electric Vehicles in St.John's, Newfoundland

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***Abstract*— Escalating rates of greenhouse gas emissions are making our planet warmer, thus triggering new climate patterns that can change the environment irreversibly. The transport sector contributes 27% of the global greenhouse gas emissions. This paper attempts to study an isolated solar PV powered charging facility, as part of a parking lot, for 20 electric vehicles in St. John's, Newfoundland. A system simulation has been carried out in HOMER software for a fully functioning system including the array size, battery storage, inverter, based on SMART EQ fortwo electric vehicles. Additionally, a MATLAB simulation is also carried out for dynamic modeling of the system. Both simulations confirmed the feasibility of the system and proper operation despite the low number of sun hours in St. John's. System design and simulation results are presented in the paper.**

Keywords—PV, Electric Vehicle (EV), Renewable energy, solar energy.

I. INTRODUCTION

Climate change mitigation and adaptation policies have helped the development of products around the world. One of the major sectors contributing to climate change is transportation. Public and private vehicles using internal combustion engines are contributing approx. 27% of the world's GHG emissions. As a result, many manufacturers are developing more environment friendly vehicles that operate on electrical drives, or hydrogen. However, integration of those technologies demands the electricity or fuel to be available at ease and at a reasonable cost. This paper investigates the potential of photovoltaic technology (PV) as an alternative to grid power as the electrical source for 20 private electric vehicles that can be used in the St. John's, NL metropolitan area. A full-scale study of the proposed system was implemented using HOMER. This study included a detailed review of the solar insolation for the area, selection of the PV type and size, inverter make and size, and battery storage sizing. The results obtained from the HOMER simulation was further developed on MATLAB for a dynamic model to study of the viability of the system a under three operating conditions: (i) direct PV run, (ii) timed cutoff and (iii) 35% SOC drop cutoff for charging. [1] [2] Maximum Power Point Tracking (MPPT) controller which is based on the perturb and observe (P&O) is proposed and simulated in MATLAB to track irradiance variation. [3]

II. SITE DETAILS AND CALCULATIONS

A. Selected Site

Parking lot is located next to the Canada National Research Council (NRC) building in the Memorial University of Newfoundland, St. John's, Newfoundland, Canada. With a total area of 7,350m2.

B. Site's solar insolation from NERL website

The solar radiation and clearness index for selected site in St. John's, Newfoundland, Canada can be seen as a monthly profile in fig 2. The clearness index is of 0.39 to 0.49 with an average of 0.44, solar insolation varying between 1.28 kWh/m^2/day to 5.14 kWh/m^2/day with average of 3.15 kWh/m^2/day.

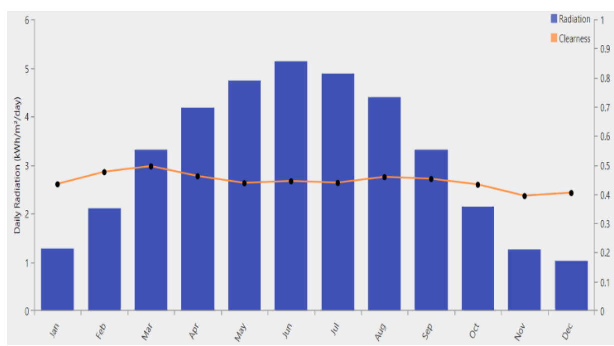

Fig 1 – Solar insolation and clearness index of selected site.

C. Site's load calculation

The system is required to supply 20 vehicles with 2.3 kW each, for a duration of 9 hours, hence we expect the daily load profile to be a constant, straight line.

Peak Load = Power per vehicle x number of vehicles
= 2.3kW x 20
= 46 kW

Total Load = Peak Load x number of duty hours
= 46 x 9
= 414 kWh/day

The proposed parking lot has operating hours between 9 AM to 5.45 PM, figure 2 illustrates the daily load chart in correlation with the operating house and figure 3 illustrates the annual load chart from HOMER.

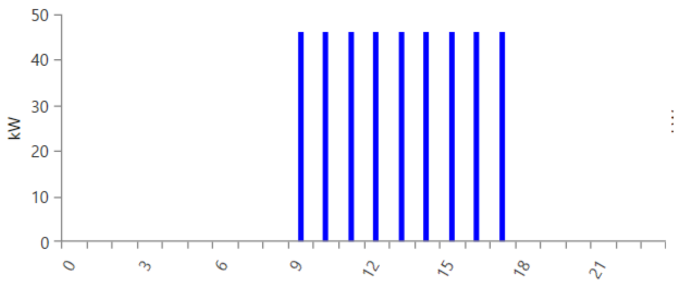

Fig 2 - Daily load chart from HOMER

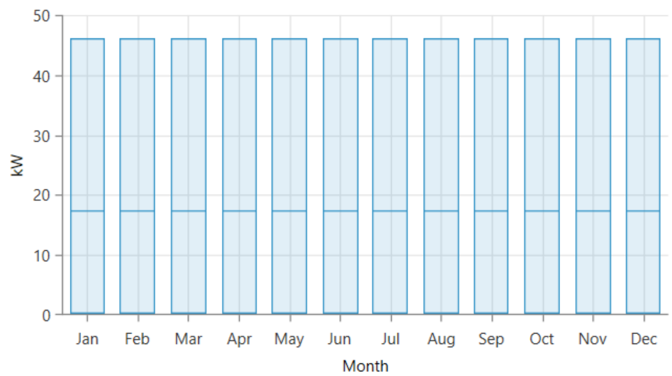

Fig 3 - Annual load chart from HOMER

D. Site's Photovoltaic panel area calculation

Average daily sunlight in St. John's = 1633 hours for 272 days.

$$Power\ Output = \frac{Energy\ usage\ per\ day}{Number\ of\ full\ sunhours\ per\ day}$$

$$Power\ Output = \frac{414\ kWh}{4.47} = 92.617\ kW$$

Power output = 92.617 kW

PV sizing considering derating factor as 0.8
= 115.771 kW

PV size array for calculated power output
= 272 Modules

PV size array for derating factor
= 340 Modules

Area Calculation
For desired power output
$272 \times 1.88 = 511.36 m^2$

Including derating factor
$340 \times 1.88 = 639.2 m^2$

Available area = 7,350 m^2

Bus voltage = 240 V

For desired power output, number of strings = 28 Strings

Number of panels in each string = 10

Voltage output = 240 V per string

Including derating factor the number of strings = 34 Strings

Number of panels in each string = 10

Voltage output = 240 V per string

III. SYSTEM SIMULATION

Hybrid Optimization of Multiple Energy Resources (HOMER) software, models micro-power systems with single or multiple power sources (e.g., photovoltaics), and helps to design off-grid and grid-connected systems by taking the factors such as the size of the components, system configurations, adequacies of the various renewable energy resources in that region into consideration. The components used in schematic are illustrated in figure 4.

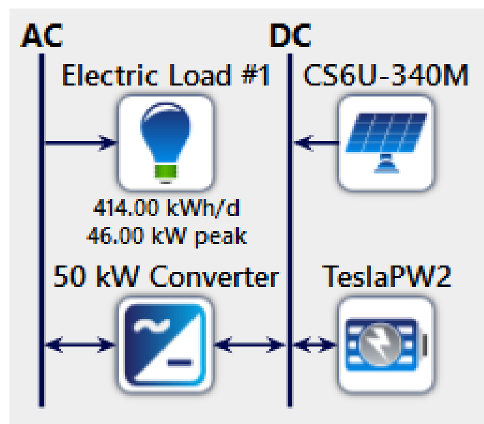

Fig 4 Schematic of proposed system in HOMER

A. Photovoltaic panel

The panel considered for this design is Canadian Solar CS6U 340M which outputs 340 W and is of 1.8 m^2 in area.

B. Battery

Tesla Powerwall 2.0 is considered as the battery for the application. The total number of batteries considered is 216 numbers.

C. Inverter

An inverter is with 50kW as output capacity as the peak load value comes to around 46kWwas considered for the application. The inverter implemented in this case is a single-phase inverter.

D. Smart EQ ForTwo – Electric Vehicle (Load)

SmartEQ ForTwo with 17.6kW lithium-ion battery pack and 4.6kW onboard charger is considered in this design. The charging rate considered is 12 km/hr at 230v and 10A.

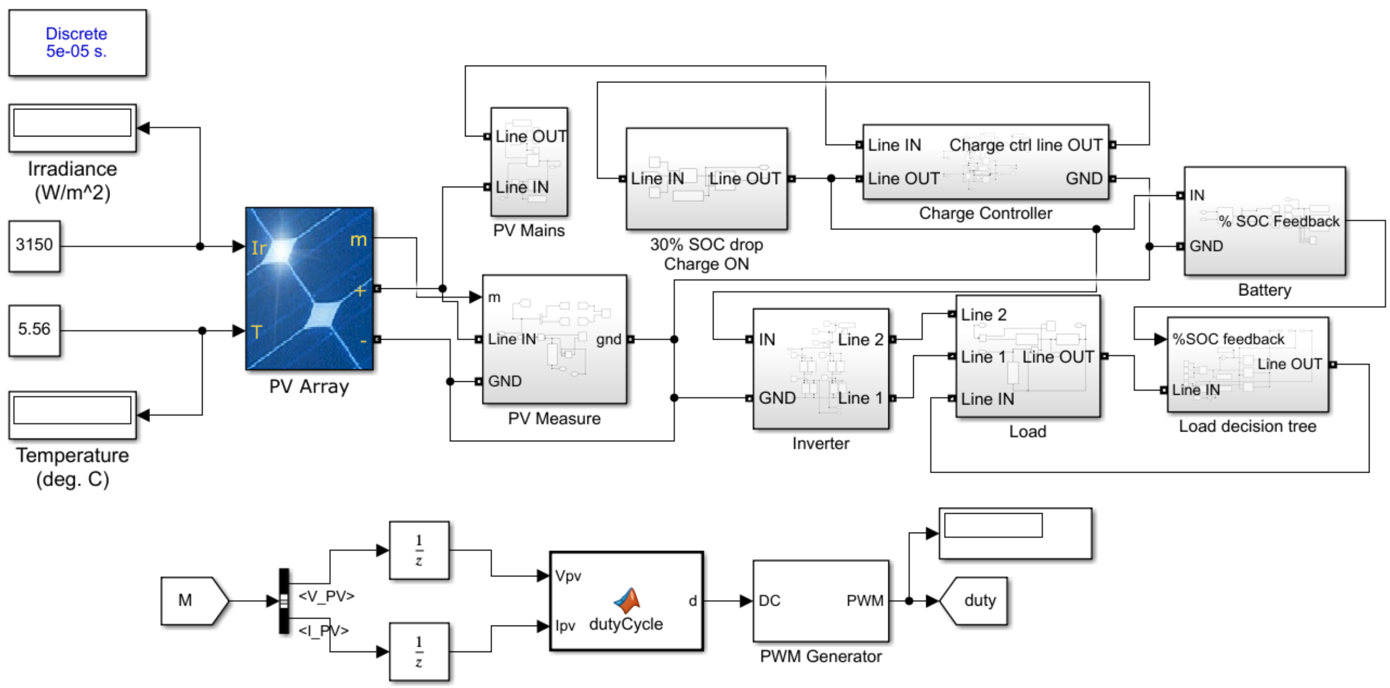

Fig. 5- Overview of simulated system

IV. Dynamic Simulation

The MATLAB simulation of the proposed architecture was executed using Simulink. It comprises various blocks - PV measure and mains block, charge controller block, battery block, inverter block, load block, load decision tree block, 35% SOC drop block, MPPT block. It incorporates an MPPT algorithm for maximized power output for variable irradiance and also on the charge and discharge control of the battery; figure 5 illustrates an overview of the simulated system.

A. PV Measure Block

It comprises current and voltage measurements to have a track on the produced power. Figure 6 illustrates the PV measure block. The values generated aids in operation of the load decision tree block.

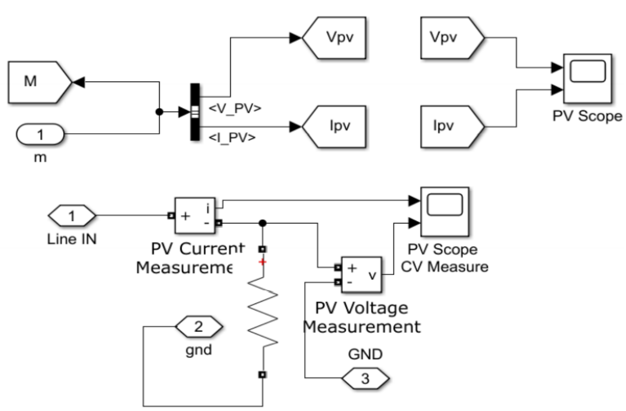

Fig 6 - Implemented PV Measure block in the system.

B. Charge Controller Block

The signal from MPPT [PWM] acts as the gate pulse for the MOSFET. This also has the charging latch and low charge override which act upon receiving values from the load decision tree block. [4]

C. Battery Block

It has the battery specification of Tesla Powerwall 2.0; nominal voltage of 220V, nominal capacity of 13.2 kWh and 60Ah. The implemented battery has an initial charge as 45%. Current, voltage and %SOC of the batteries are monitored during the charging and discharging process and are used as feedback to other blocks for its operation. Figure 7 illustrates the implemented battery block in the system.

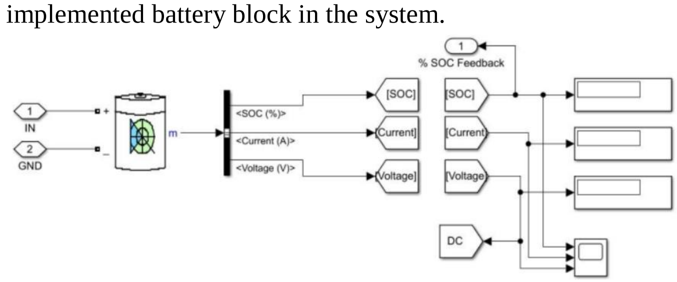

Fig 7 Implemented battery block in the system.

D. Inverter

This block was designed using 4 IGBTs and diodes to operate in forward biased condition. At a given point of time two IGBTs fire in one direction and the other two in the next consecutive cycle. The gate pulse is provided by a pulse generator. Figure 8 illustrates the inverter design in the proposed system. [5]

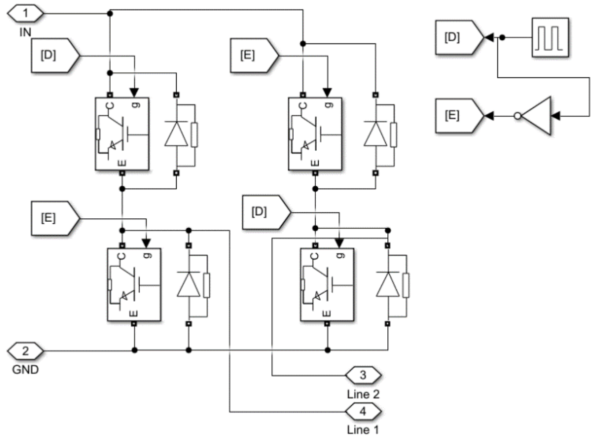

Fig 8 - Implemented inverter design in the system

E. *Load decision tree*

The purpose of this block is to have control on load run based on State of Charge [SOC] of battery, timed cutoff and overrun in case of high load demand. Figure 3 illustrates the load decision tree block. This also has the trigger signal for turning on the charger when the batteries SOC drops below 35%. Figure 9 Illustrates the load decision tree [6][7]

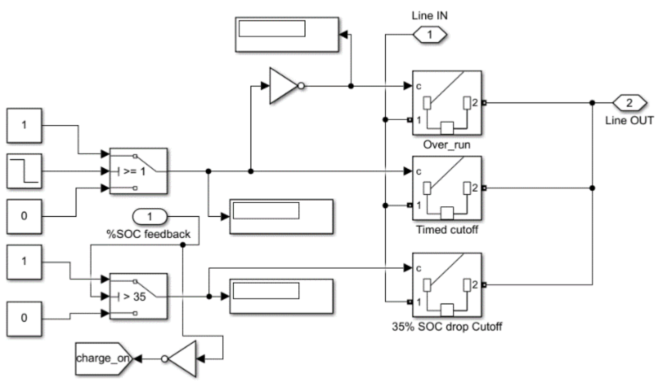

Fig 9 - Implemented lead decision tree in the system.

F. *35% SOC charge block*

This block has its trigger signal from the load decision latch. If the battery's SOC drops down to below 35%, the system switches the charging mechanism, and the battery starts to charge. Figure 10 illustrates the 35% SOC drop charging. This condition is continued till the trigger signal from the load decision tree is back to LOW. This happens when the battery's SOC is more than the threshold. [8]

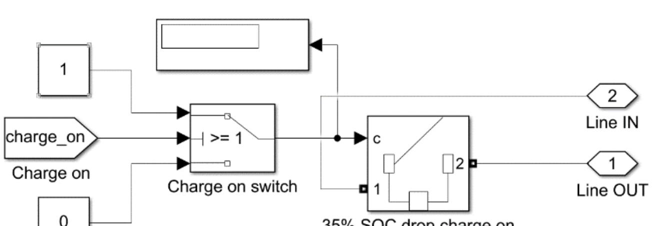

Fig 10- Implemented SOC charge block in the system.

G. *MPPT Algorithm*

The concept of Maximum power point tracking (MPPT) is adjusting PV impedance based on various irradiance to extract maximum power from PV panel. The MPPT controller in this simulation is working based on the Perturbation & Observation (P&O) algorithm. In the P&O algorithm, the voltage is continuously perturbed, and the inverter duty cycle will be changed based on the output observation. This algorithm is best to track the maximum point even in severe drop or jump in the irradiance. [9] [10] Figure 11 illustrates the MPPT algorithm.

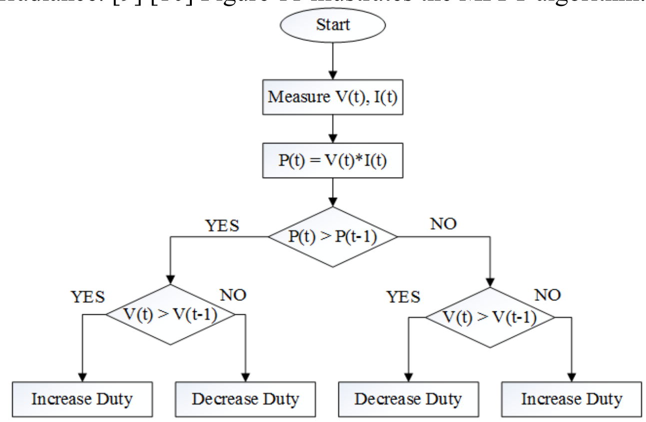

Fig 11 - Implemented MPPT algorithm

Figure 12 illustrates the charging and discharging of batteries. The battery is in charge mode for a given point of time and it is on discharging mode and on crossing a certain point of time it goes back to charging mode.

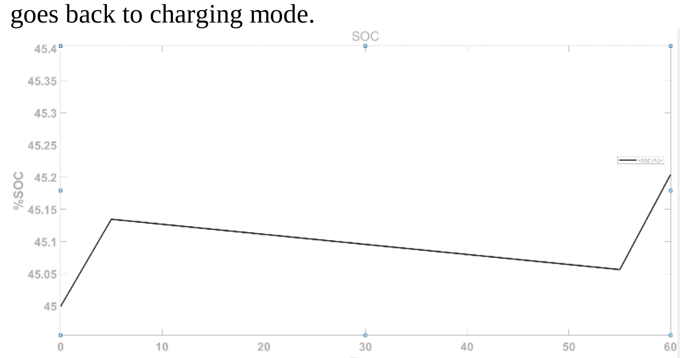

Fig 12 - SOC of battery during charging and discharging mode.

Figure 13 illustrates the load's current graph and figure 14 illustrates load's voltage graph. The load, in this case, is an AC load and the power from the battery is converted to AC by using an inverter.

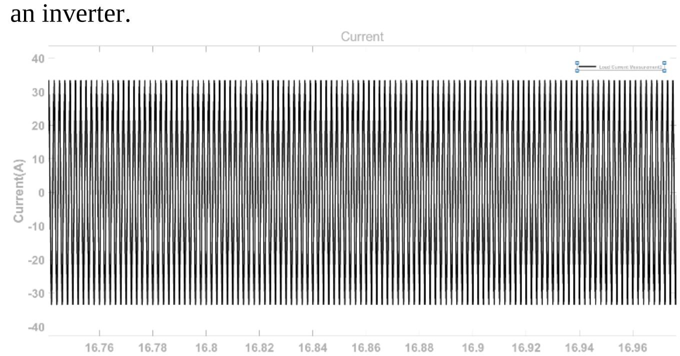

Fig 13 - Implemented system's load current graph

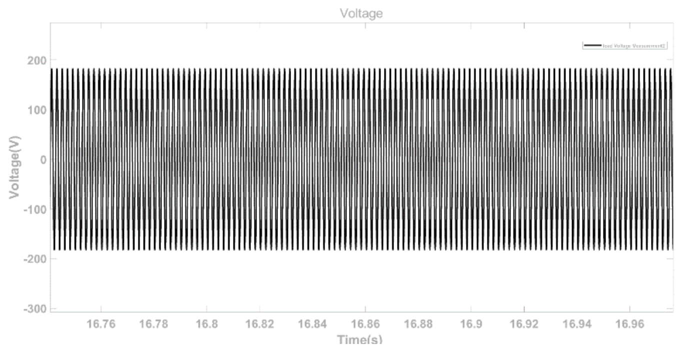

Fig 14 Load's voltage graph.

V. CONCLUSION

Dynamic modelling of an Isolated Solar Powered Charging Facility for 20 Electric Vehicles in St. John's, Newfoundland. The solar insolation for Newfoundland from figure 1 is 3.15 kWh/m2/day, number of PV panels considered are 340W modules implemented in 34 strings with 10 panels in each string. A commercially available inverter of 50 kW capacity was incorporated with 216 Tesla Powerwall 2.0 batteries each of 220 V and 60 Ah. The implemented simulation consisted of three main operating conditions: (i) direct PV run - in this mode the produced power was directly utilized for operation of load, (ii) timed cutoff - since the parking lot was closed by 6pm the system had a timed cutoff loop which would assist primarily in charging the batteries and (iii) 35% SOC drop cutoff for charging - this condition is executed when the loads energy demand is high and the SOC of battery is <=35 %, they system cuts off the load and charges the battery until it reaches more than the threshold. This makes this system an apt implementation for an isolated parking lot since it is self-sufficient. The implemented system has the scalability factor - can be extended from one parking lot to citywide parking lots. Further this research would be directed towards implementing the V2X concept where parking lot(s) can be used for powering a building or a locality or a city. [11] [12]

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