Dynamic Modeling, Simulation and Data Logging of a Hybrid Power System for a Remote House in Qinghai Province in China

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Outline

- Motivation
- Introduction
- Research Objective
- System Sizing
- Dynamic Modeling and Simulation
- Data Logging and Visualization
- Conclusion
- Future Work

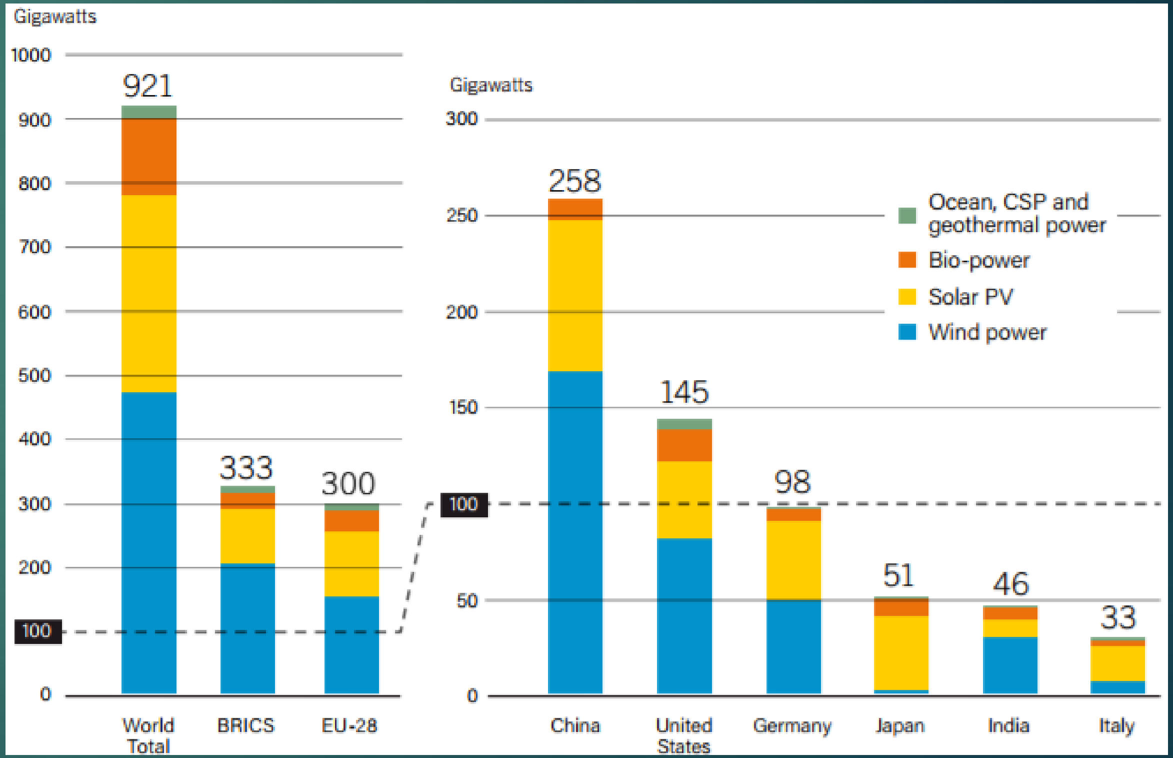
1. Motivation

- Environmental policies in China not suitable for traditional power generation
- Decreasing coal storage increases the coal price in China
- Supportive government policies for renewable energy
- On-grid hybrid power system not permitted due to no feed-in tariff policy
- Off-grid hybrid power systems already successful in some remote communities

2. Introduction

- Development of Renewable Energy in China

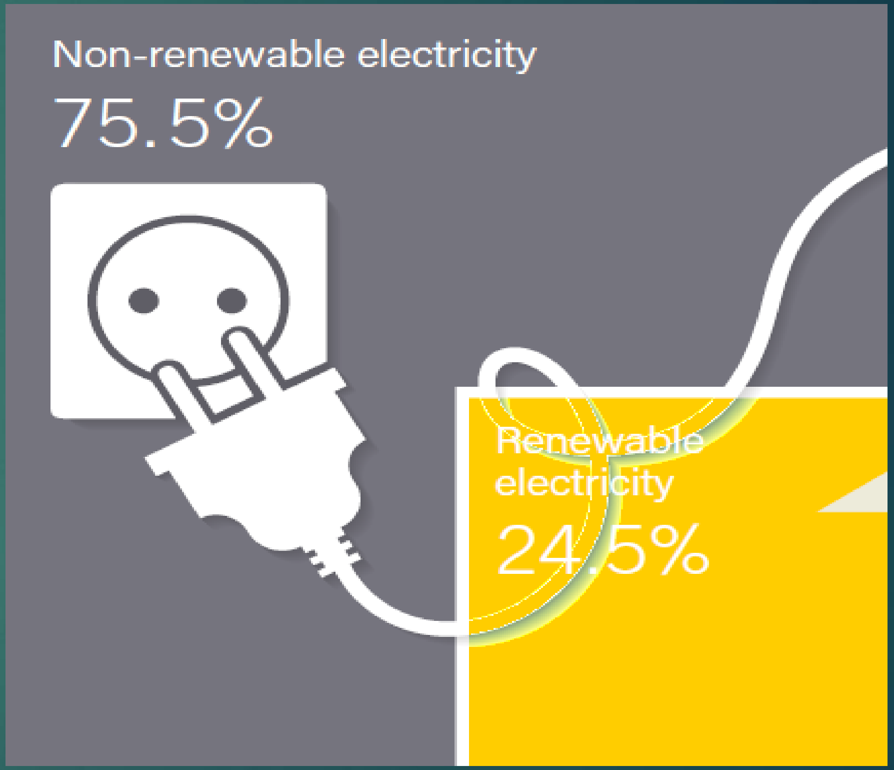
Supportive government policies above boost up the development of the renewable energy in China. The levelized costs of solar energy (0.075-0.155 USD/kWh) and wind energy (0.05-0.07 USD/kWh) are becoming affordable.



2. Introduction

- Development of Traditional Energy

Traditional energy takes 75.5% global power generation, leading to huge amount of green house gas emission [4]. Due to environmental restriction, the newly installed traditional generation is 38% of the global installation in 2016 [4].



2. Introduction

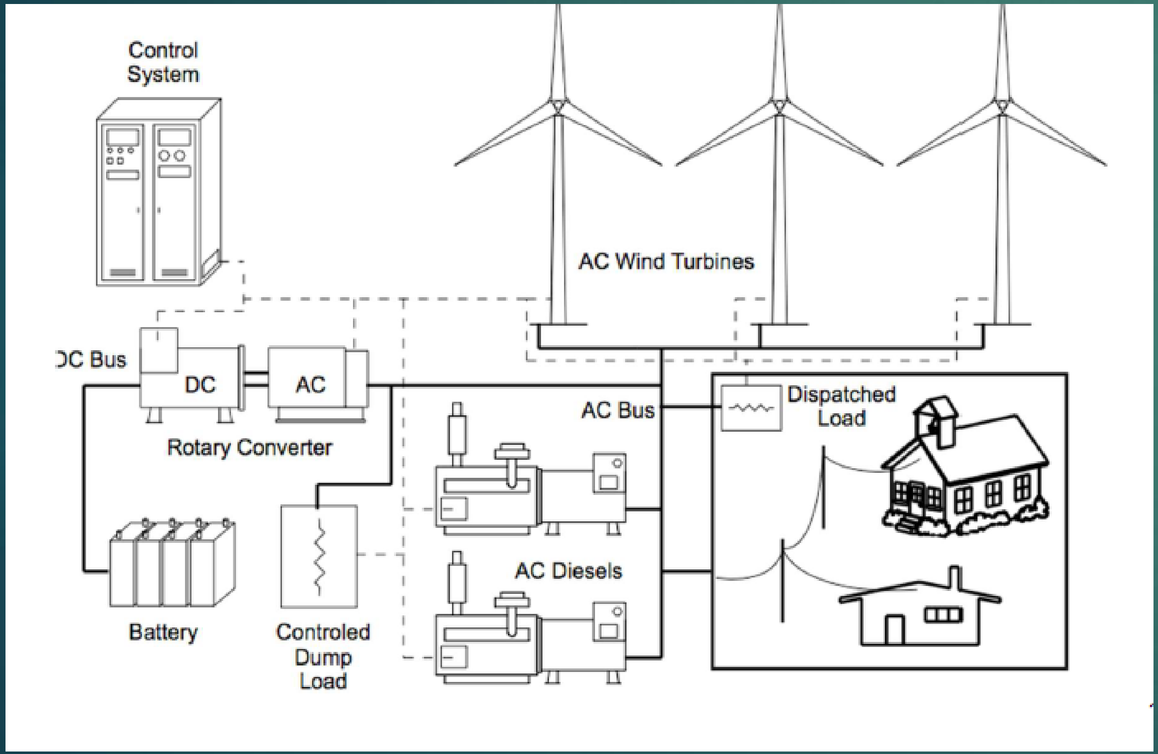
- Hybrid Power Systems

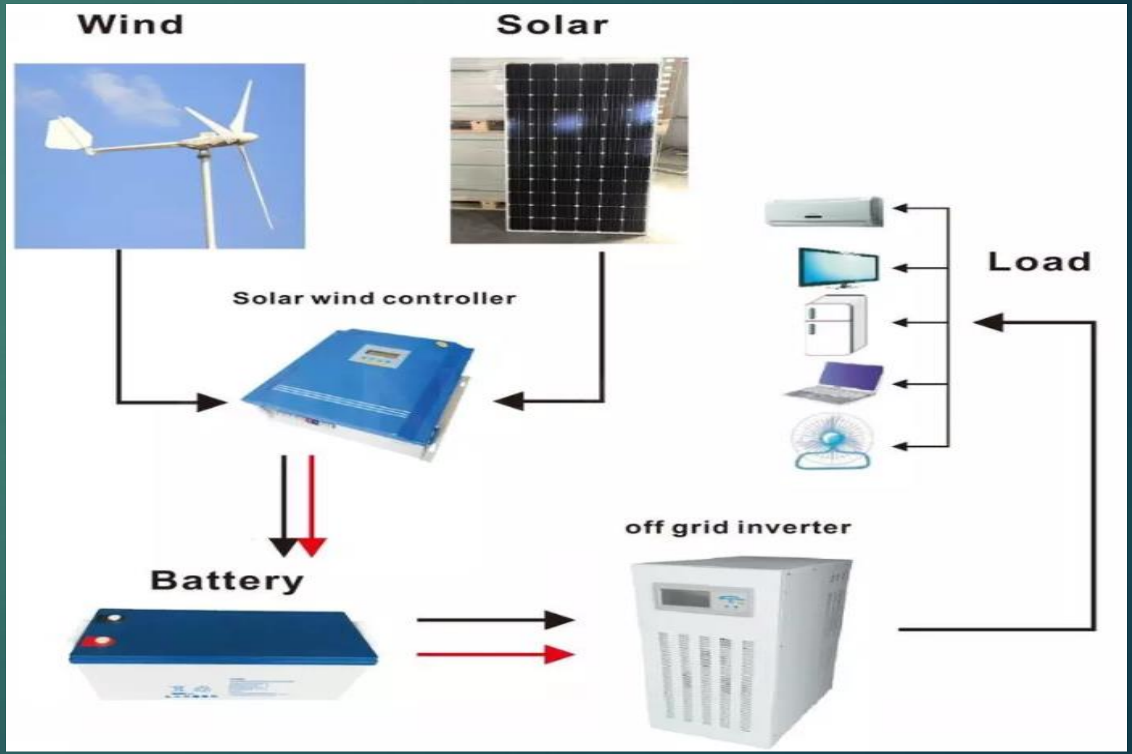
A hybrid power systems include traditional generation and at least one renewable generation. It includes [1]:

- On-grid hybrid power system: The hybrid power systems that can supply and receive power to and from power grids.
- Off-grid hybrid power systems: The hybrid power systems isolated from power grids.

2. Introduction

- Hybrid Power Systems





3. Research Objectives

- Size a hybrid power system with high renewable penetration and minimum cost
- Build the dynamic model and its control system based on the sizing result
- Test the model based on real-time conditions
- Design a low-cost data logging system for an isolated power system

4. System Sizing

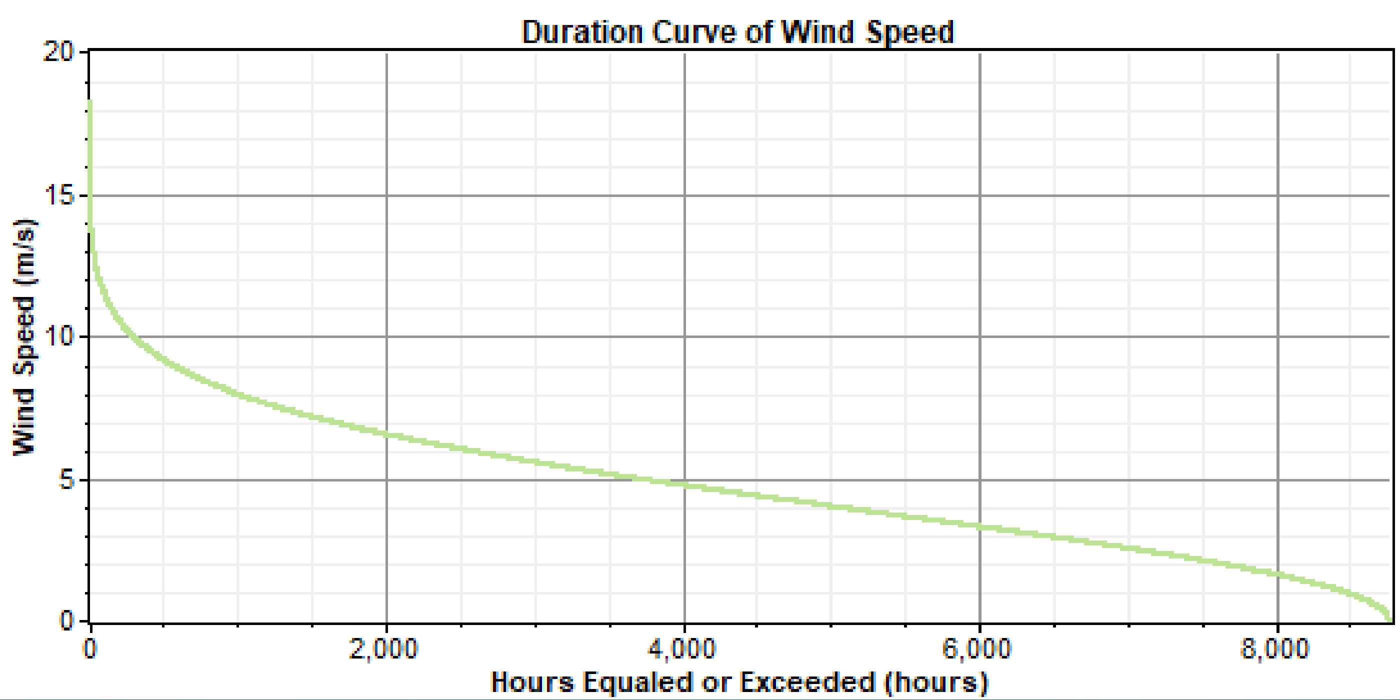
- Site Location

The site located at a remote area in China. Its coordination is 37º50’N, 101º58’E

4. System Sizing

- Climate Data of Location

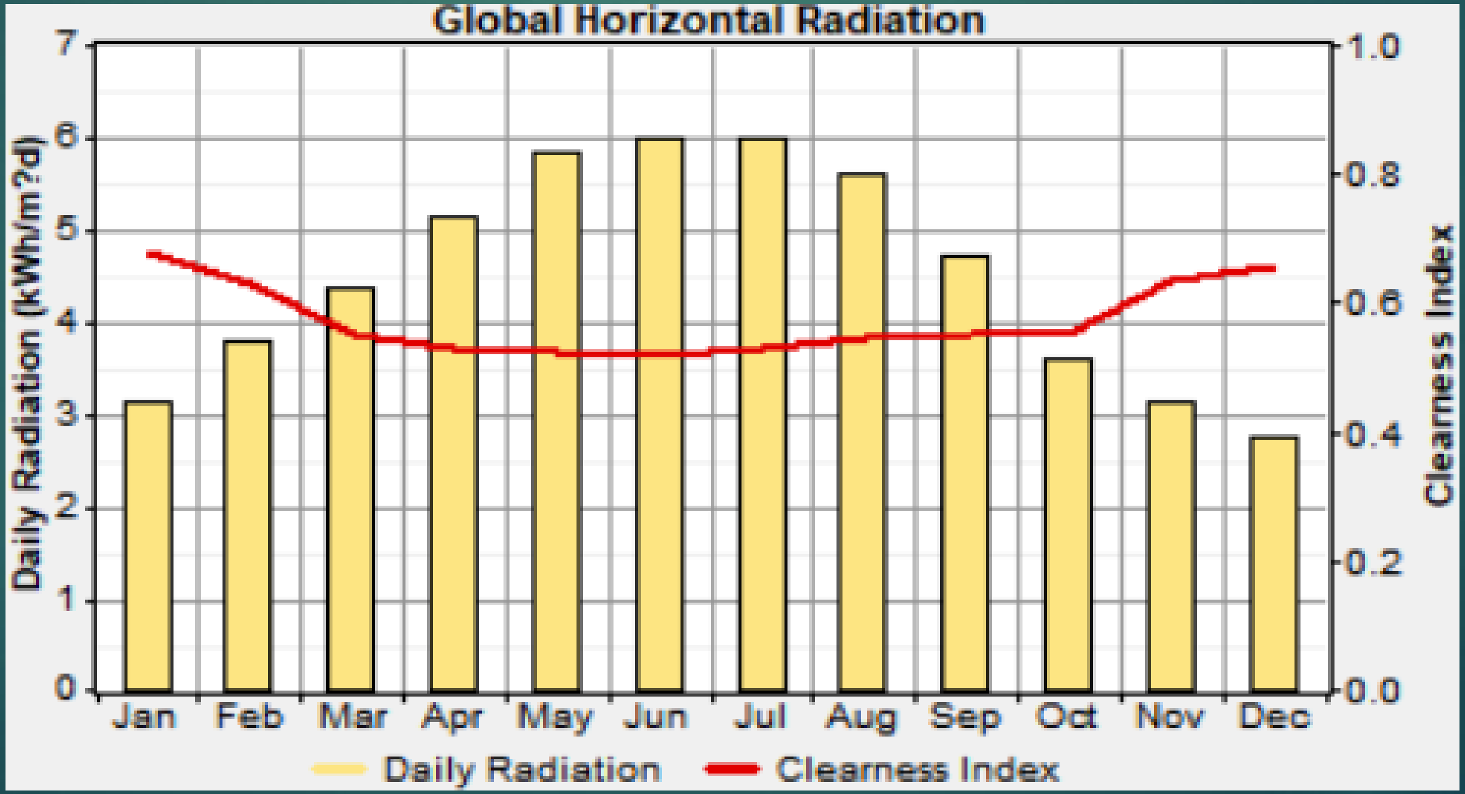
  More than 3000 hours when wind speed larger than 3m/s. Results in 200W/m^2 wind power density



4. System Sizing

- Climate Data of Location

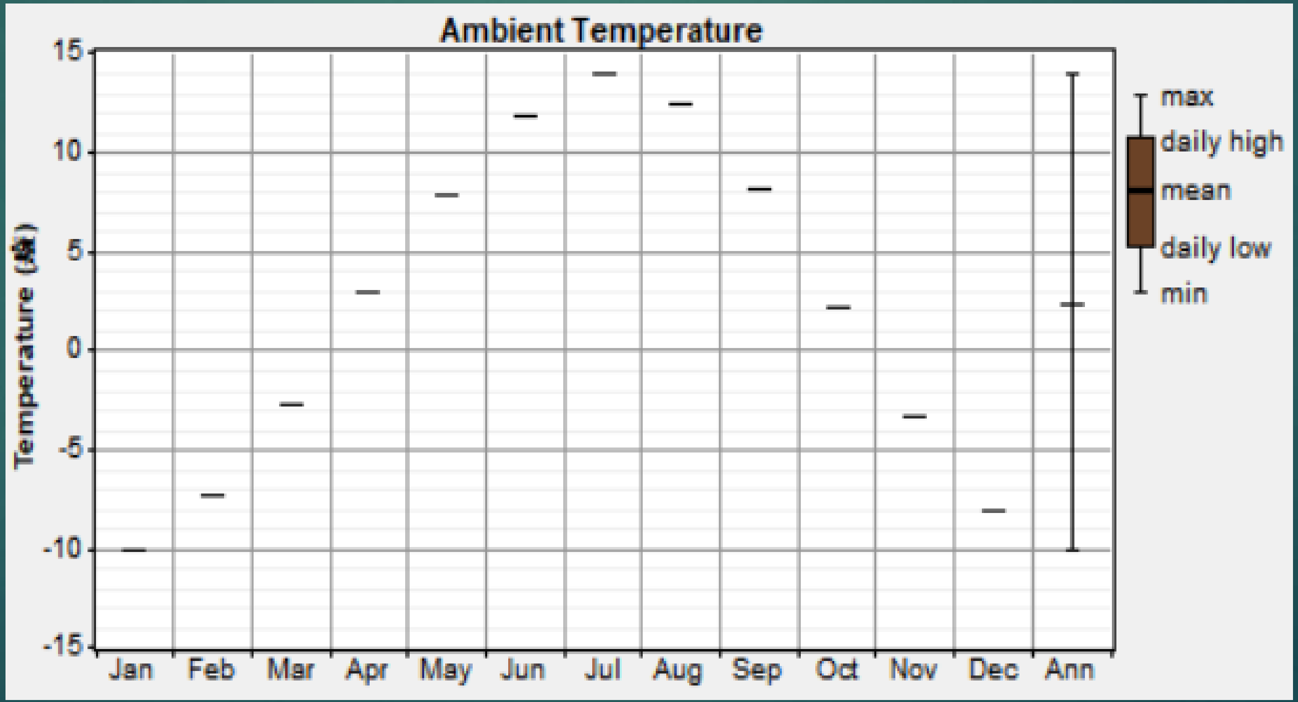
The average daily solar irradiance is 4.51kWh/$m^2 \cdot day$ (> 3kWh/ $m^2 \cdot day$)



4. System Sizing

- Climate Data of Location

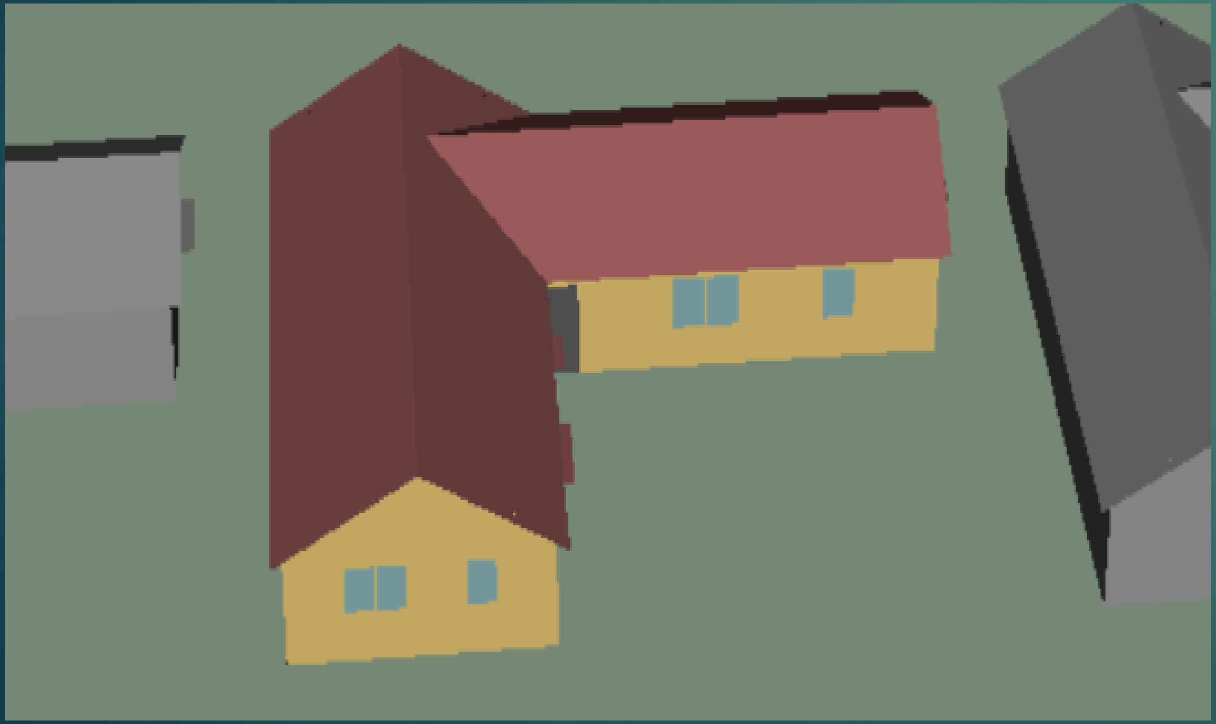
The overall temperature is relatively low around summer. Under same radiation the lower the temperature, the higher the generated solar power.

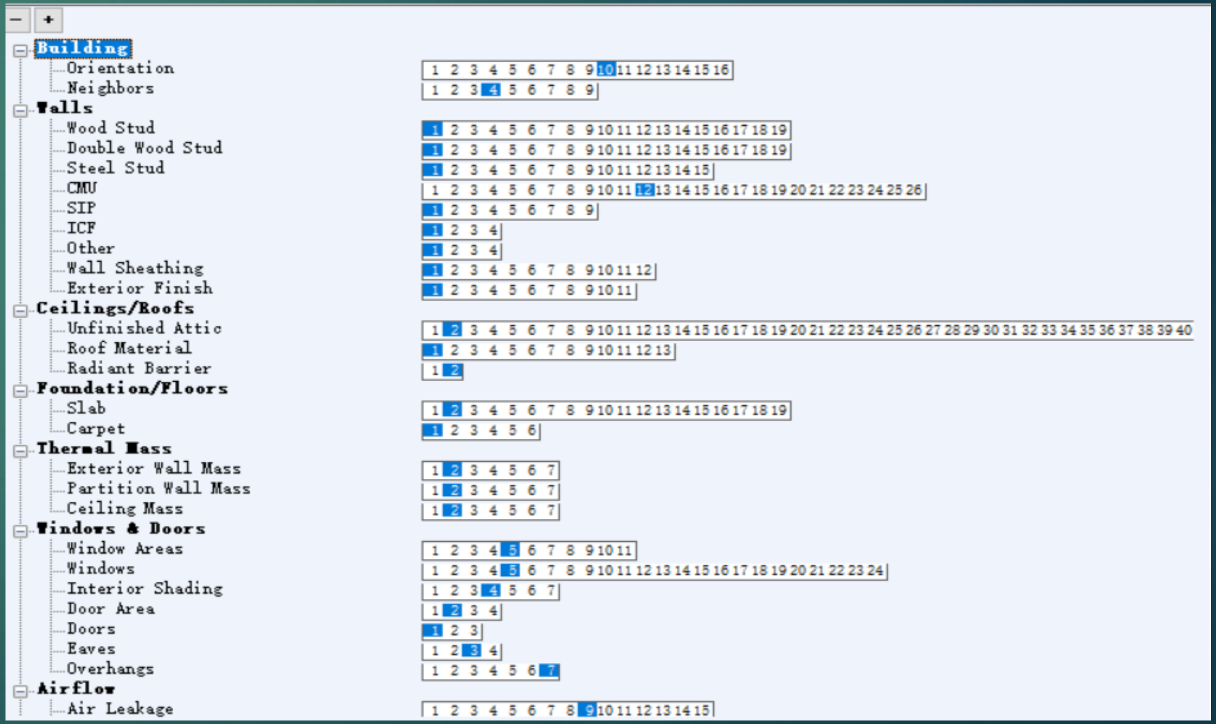


4. System Sizing

- Primary Load Data Generation

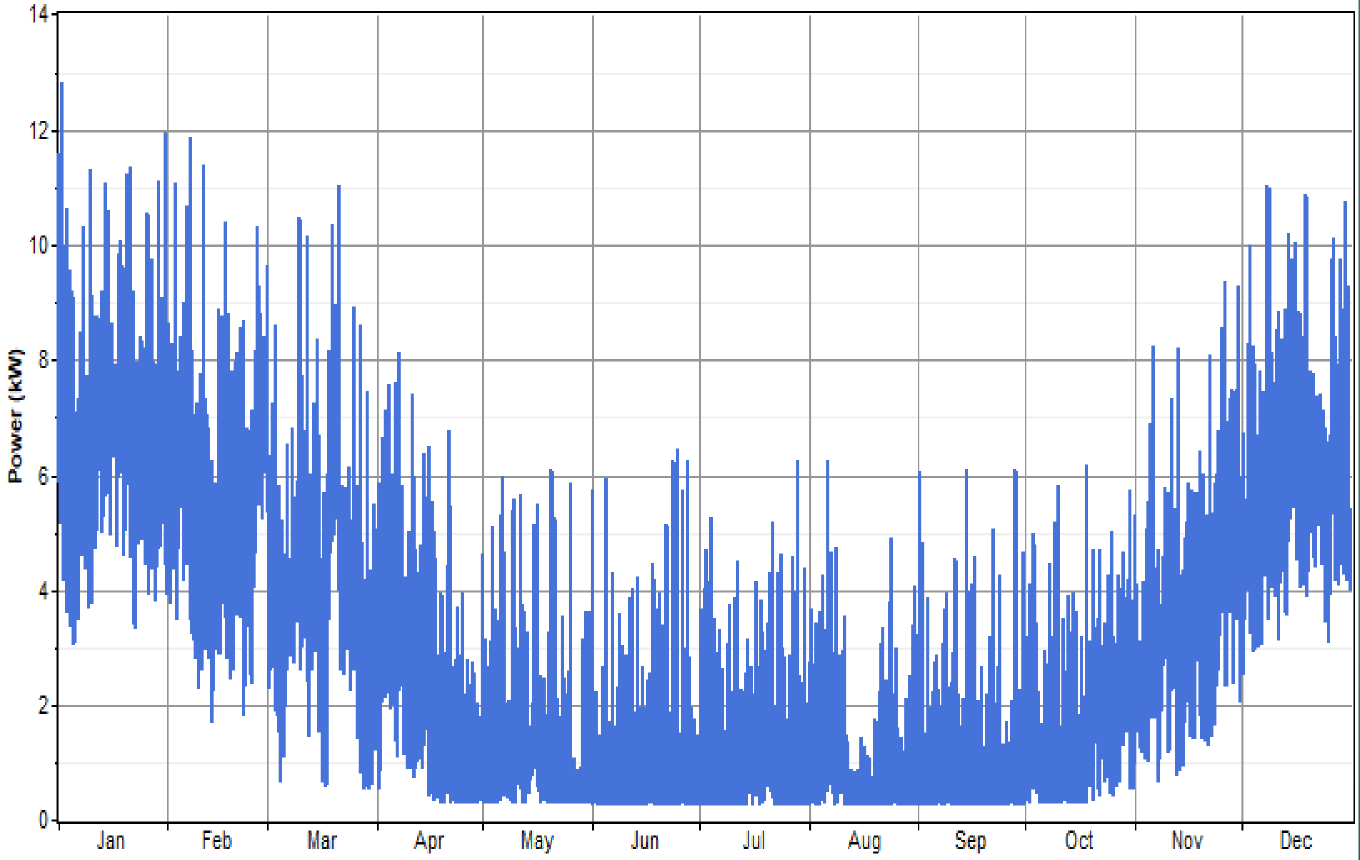
BEopt is chosen because of detailed options for thermal insulation and load

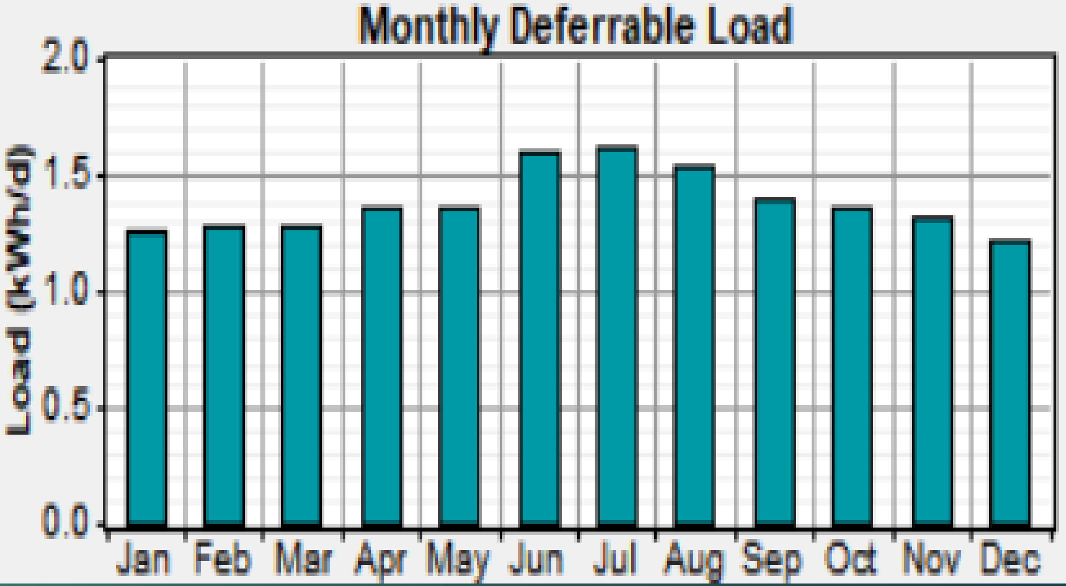




4. System Sizing

- Primary and Deferrable Load Data



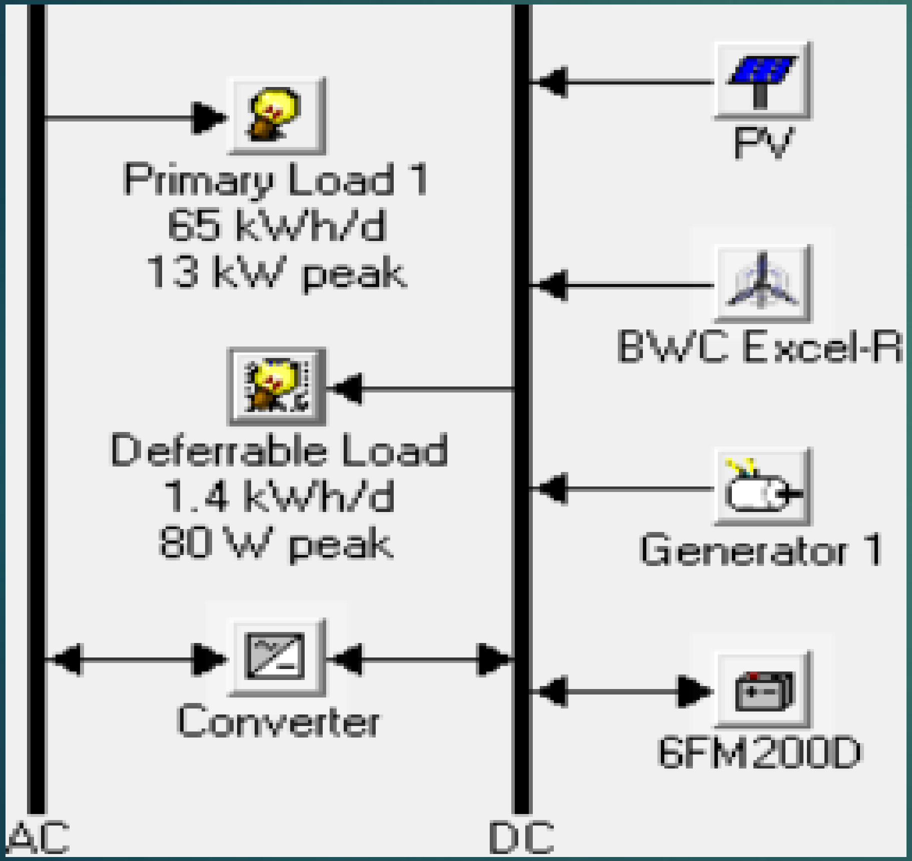


$$H_{dynamic} = Vertical\ Lift + Friction\ Loss + Tank\ Pressure$$

$$Required\ Renewable\ Power = \frac{\rho m g H_{dynamic}}{0.7\eta_{PV}\eta_{mppt}\eta_{BB}\eta_{PM}}$$

4. System Sizing

- System Configuration and Sizing Results



Sensitivity Results Optimization Results

Double click on a system below for

Categoriz Overall

PV (kW)	XLR	Label (kW)	6FM20...	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Diesel (L)	Label (hrs)
13....		8	20	15	CC	$ 28,595	10,187	$ 158,824	0.509	0.62	4,666	1,867
13....		8	20	15	CC	$ 27,935	10,250	$ 158,968	0.509	0.60	4,726	1,893
13....		8	24	15	CC	$ 30,195	10,074	$ 158,977	0.510	0.62	4,537	1,811
13....		8	24	15	CC	$ 29,535	10,140	$ 159,162	0.510	0.61	4,600	1,831
13....		8	16	15	CC	$ 26,995	10,354	$ 159,357	0.511	0.61	4,881	1,969
13....		8	16	15	CC	$ 26,335	10,421	$ 159,545	0.511	0.59	4,934	1,989
13....		8	28	15	CC	$ 31,795	10,003	$ 159,665	0.512	0.63	4,466	1,779
10....	1	7	20	15	CC	$ 50,995	8,513	$ 159,818	0.512	0.73	3,439	1,510
11....	1	7	16	15	CC	$ 50,055	8,591	$ 159,876	0.512	0.73	3,555	1,573
11....	1	7	20	15	CC	$ 51,655	8,467	$ 159,890	0.513	0.74	3,382	1,482
13....		7	48	15	CC	$ 39,495	9,422	$ 159,944	0.513	0.65	3,989	1,736
10....	1	7	16	15	CC	$ 49,395	8,648	$ 159,950	0.513	0.72	3,617	1,604
13....		8	28	15	CC	$ 31,135	10,084	$ 160,038	0.513	0.61	4,541	1,806
9.92	1	7	20	15	CC	$ 50,335	8,593	$ 160,188	0.513	0.72	3,515	1,545
9.92	1	7	16	15	CC	$ 48,735	8,719	$ 160,188	0.513	0.71	3,680	1,630
9.30	1	7	16	15	CC	$ 48,075	8,788	$ 160,414	0.514	0.70	3,750	1,663
13....		8	32	15	CC	$ 33,395	9,941	$ 160,480	0.514	0.63	4,394	1,748
9.30	1	7	20	15	CC	$ 49,675	8,668	$ 160,485	0.514	0.70	3,611	1,595
9.92	1	7	12	15	CC	$ 47,135	8,867	$ 160,485	0.514	0.70	3,907	1,759
10....	1	7	24	15	CC	$ 52,595	8,441	$ 160,494	0.514	0.74	3,334	1,461
11....	1	7	24	15	CC	$ 53,255	8,396	$ 160,582	0.515	0.75	3,275	1,434

4. System Sizing

- Cash Flow of Selected Power System

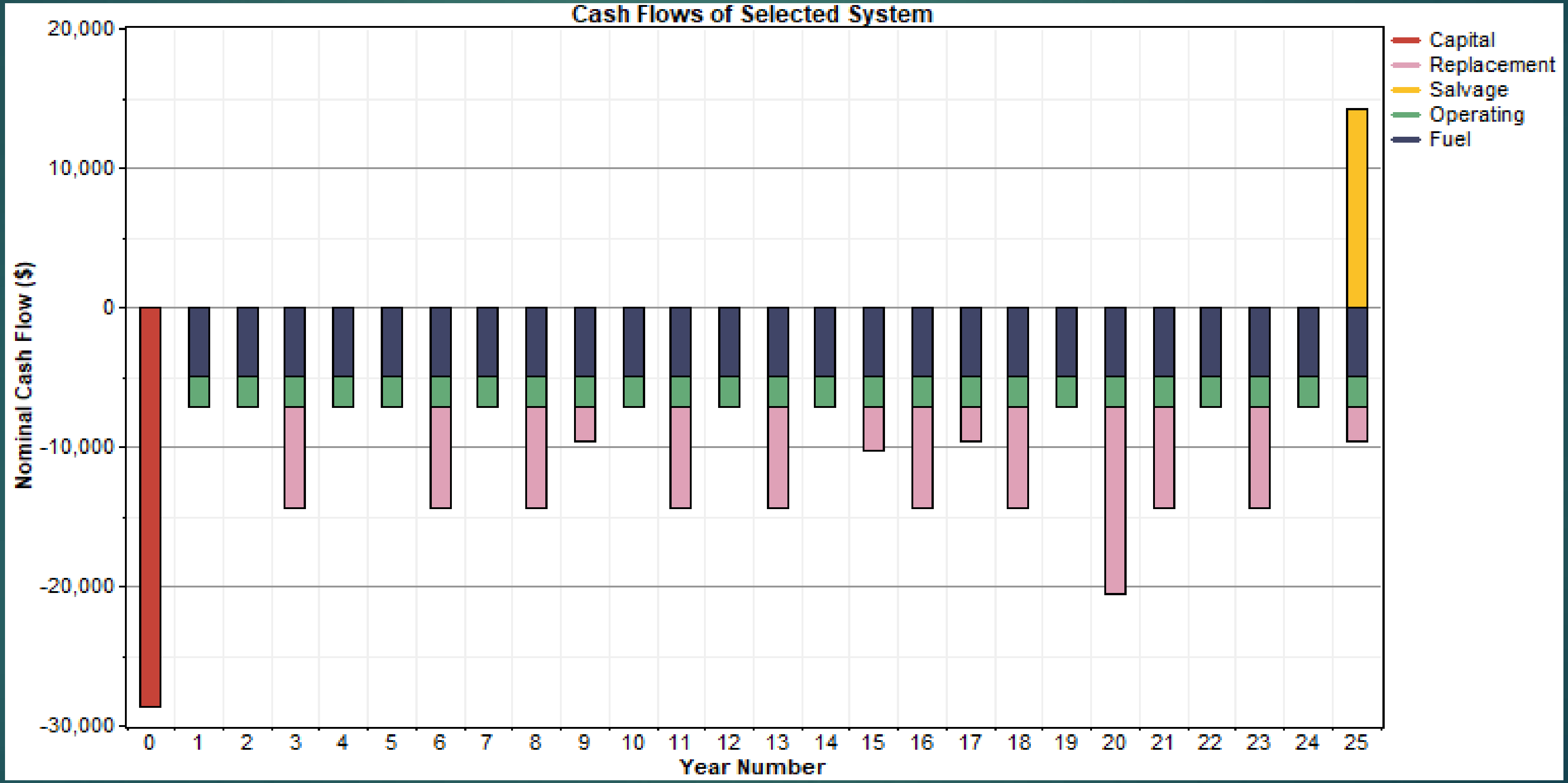


Figure 13 Cash Flow of Selected System

5. Dynamic Modeling and Simulation

- General System Model

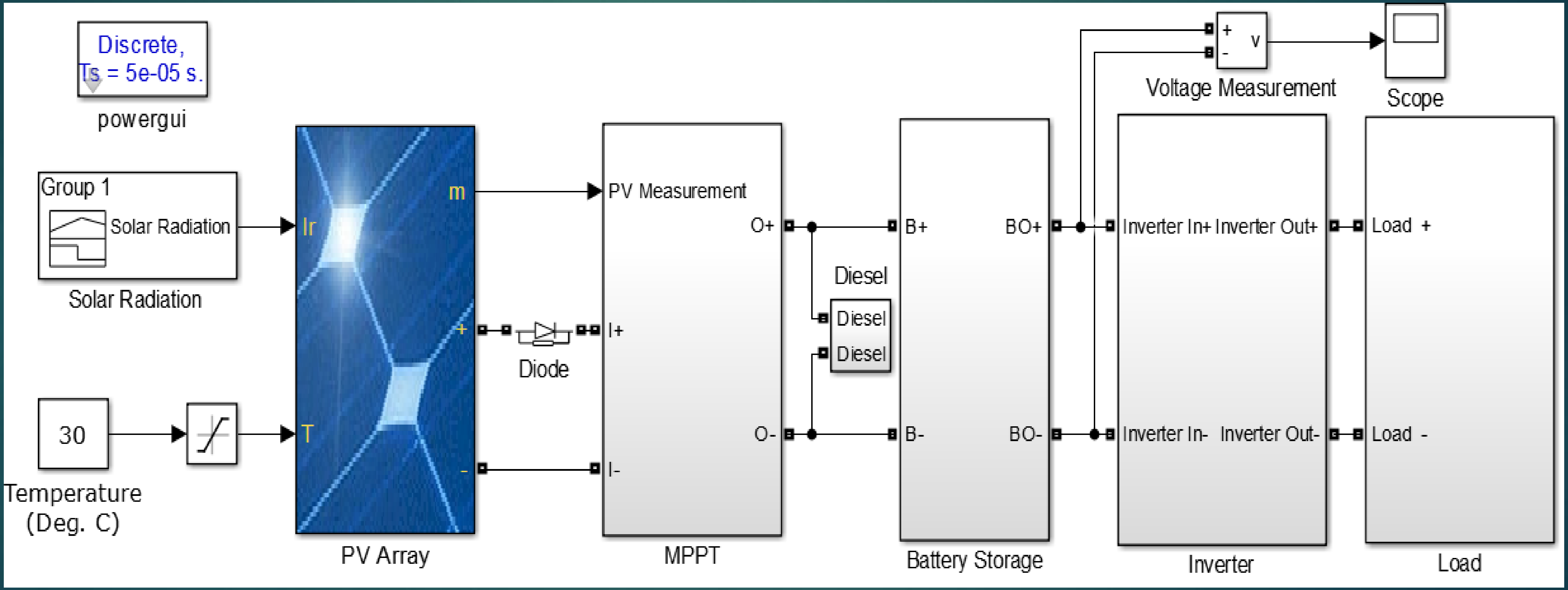


Figure 14 General System Model

5. Dynamic Modeling and Simulation

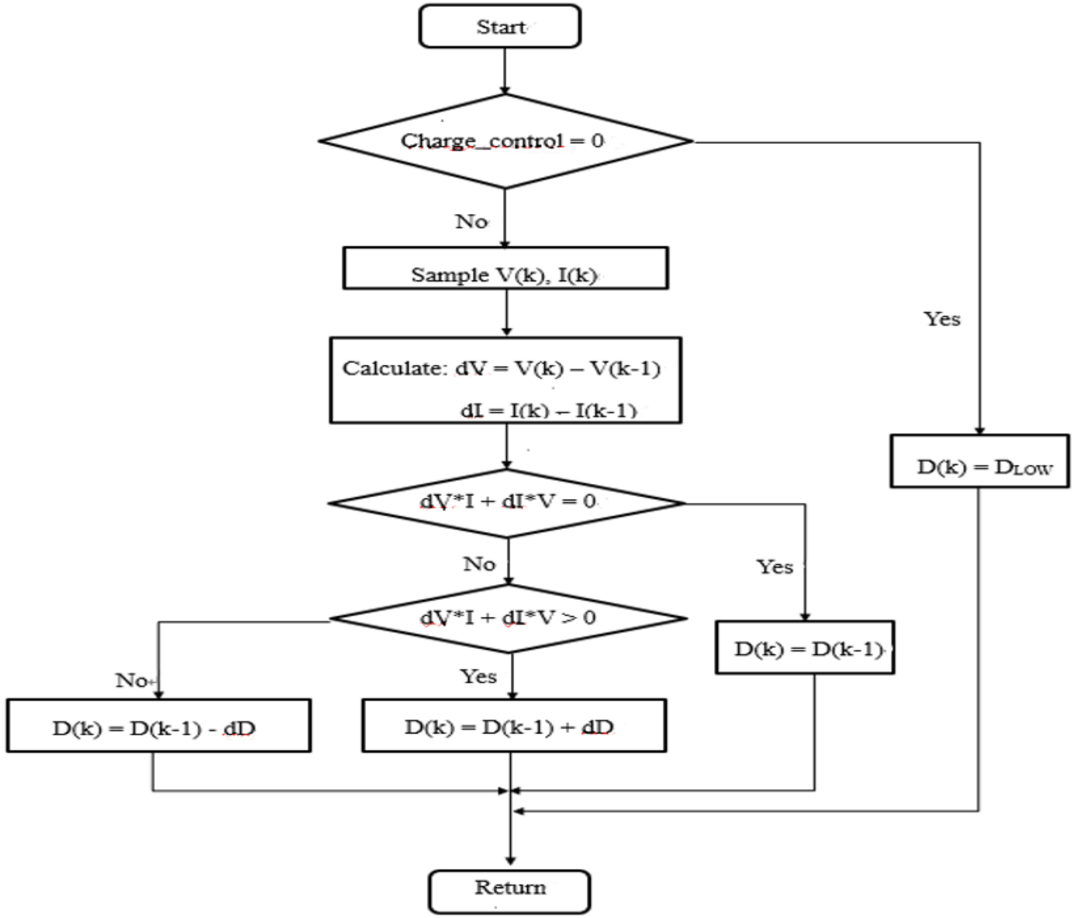
- Dynamic Model of MPPT

$$L = \frac{V_{in}(V_{out}-V_{in})}{\Delta I_l f_s V_{out}} \quad (5.1)$$

$$\Delta I_l = \frac{(0.2\sim0.4) f_s V_{out}}{V_{in}} \quad (5.2)$$

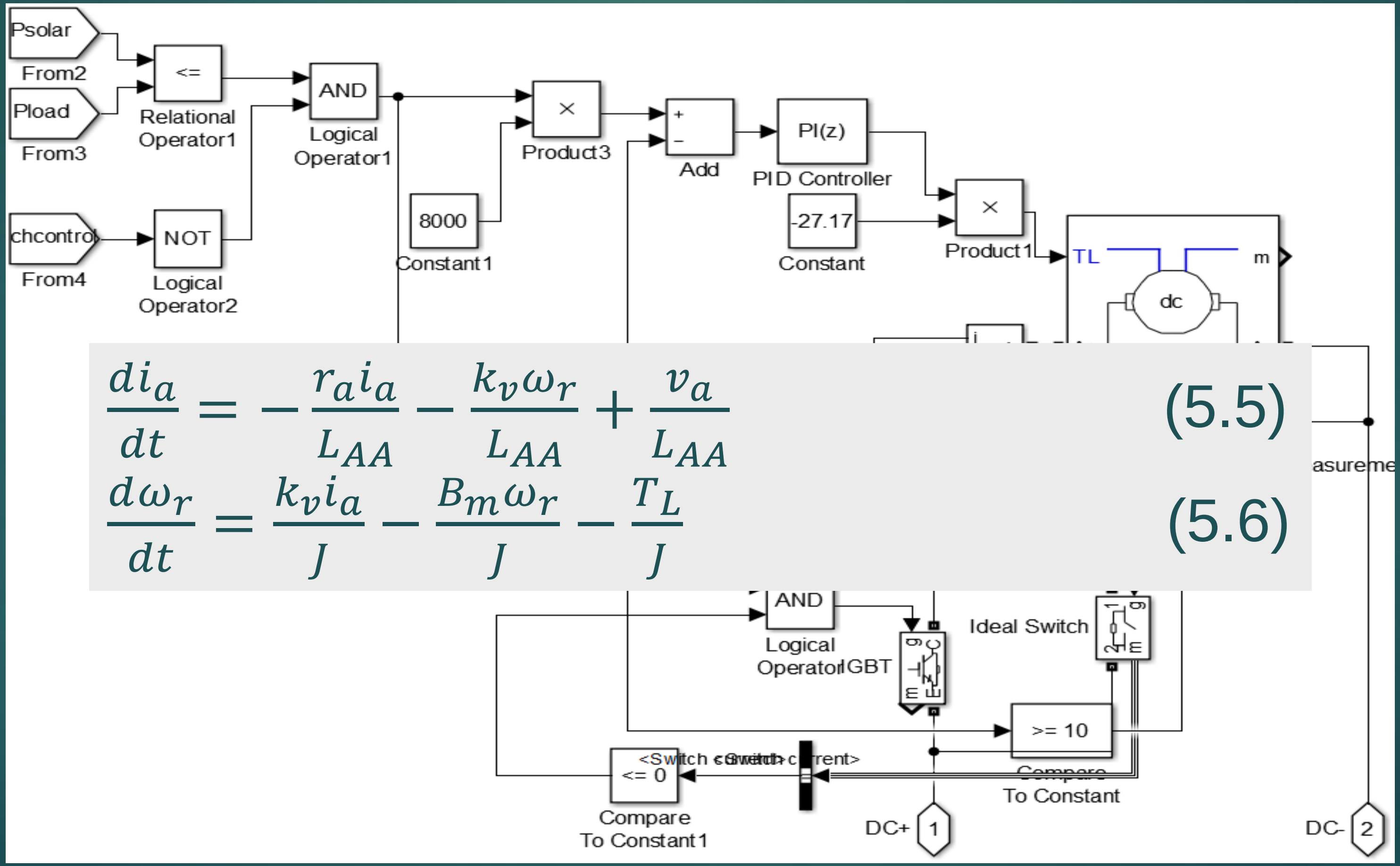
$$\Delta V_{PVmppt} = 0.05 V_{mppt} \quad (5.3)$$

$$\Delta V_{PVmppt} = \frac{P_{mppt}}{2 f_g C_{dc} V_{mppt}} \quad (5.4)$$



5. Dynamic Modeling and Simulation

- Dynamic Model of Diesel Generator



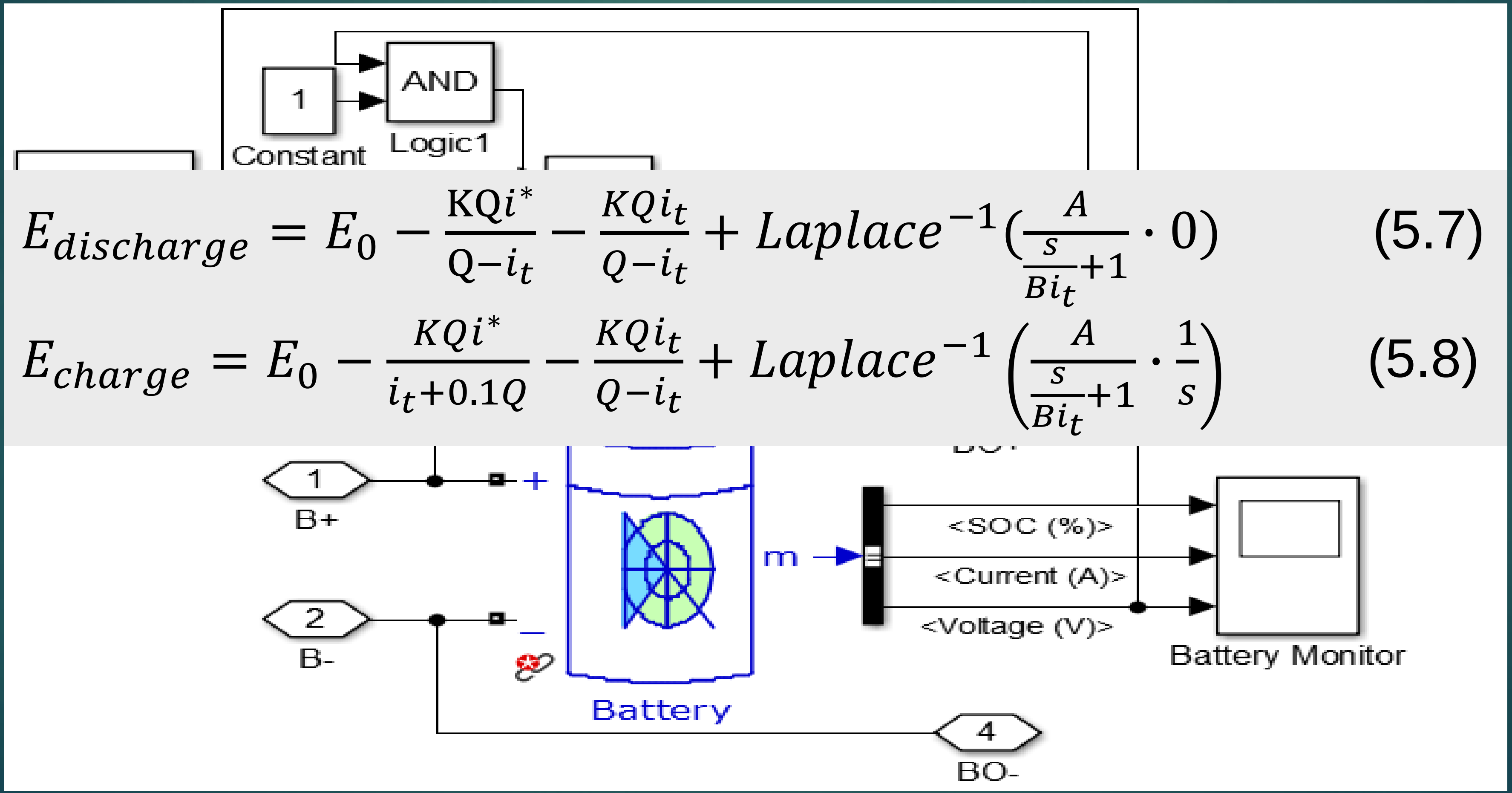
$$\frac{di_a}{dt} = -\frac{r_a i_a}{L_{AA}} - \frac{k_v \omega_r}{L_{AA}} + \frac{v_a}{L_{AA}} \quad (5.5)$$

$$\frac{d\omega_r}{dt} = \frac{k_v i_a}{J} - \frac{B_m \omega_r}{J} - \frac{T_L}{J} \quad (5.6)$$

Figure 17 Diesel Generator Model

5. Dynamic Modeling and Simulation

- Dynamic Model of Battery Storage



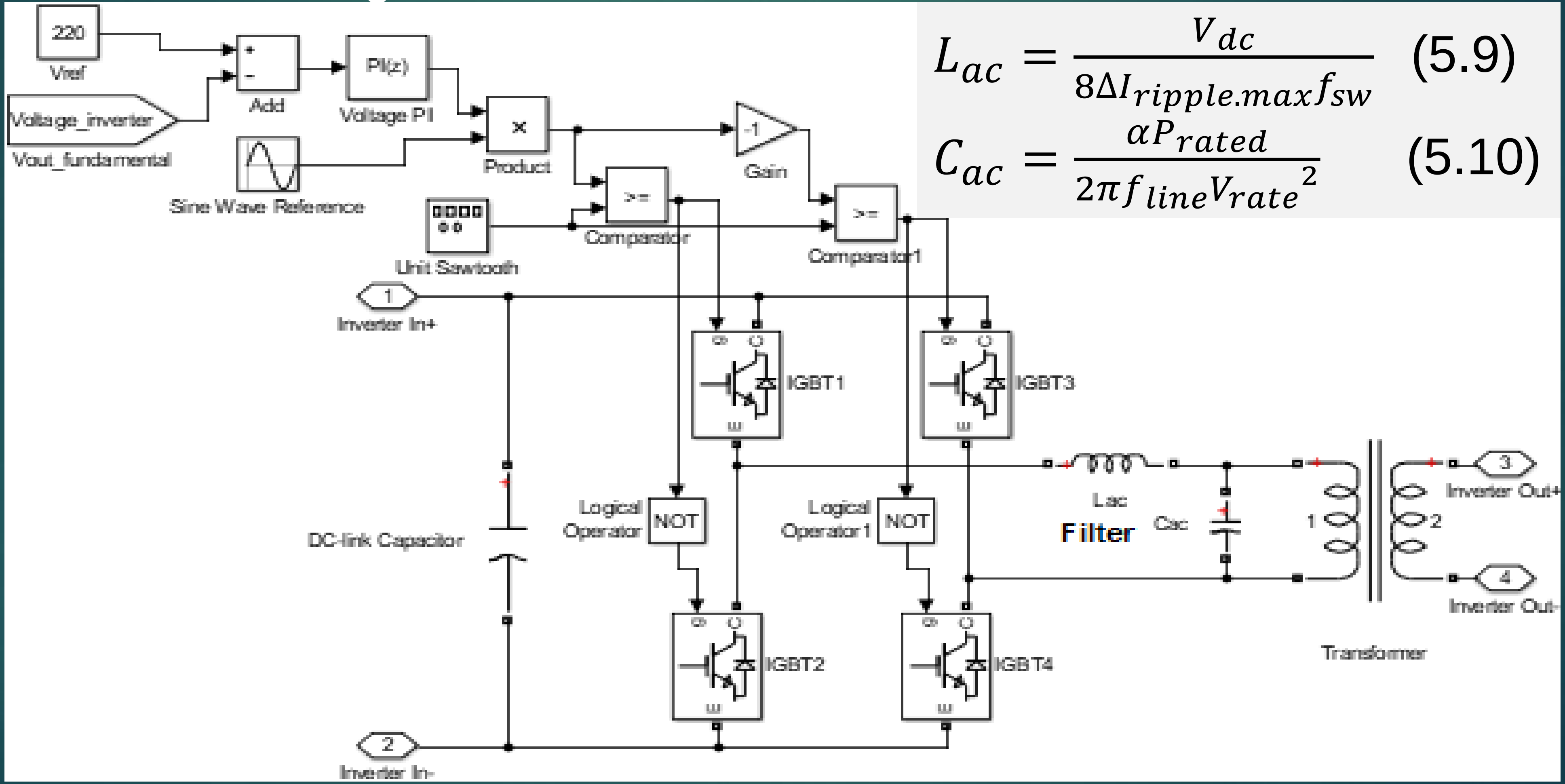
$$E_{discharge} = E_0 - \frac{KQi^*}{Q-i_t} - \frac{KQi_t}{Q-i_t} + Laplace^{-1}\left(\frac{A}{\frac{s}{Bi_t}+1} \cdot 0\right) \quad (5.7)$$

$$E_{charge} = E_0 - \frac{KQi^*}{i_t+0.1Q} - \frac{KQi_t}{Q-i_t} + Laplace^{-1}\left(\frac{A}{\frac{s}{Bi_t}+1} \cdot \frac{1}{s}\right) \quad (5.8)$$

Figure 18 Battery Model

5. Dynamic Modeling and Simulation

- Dynamic Model of Single-Phase Inverter



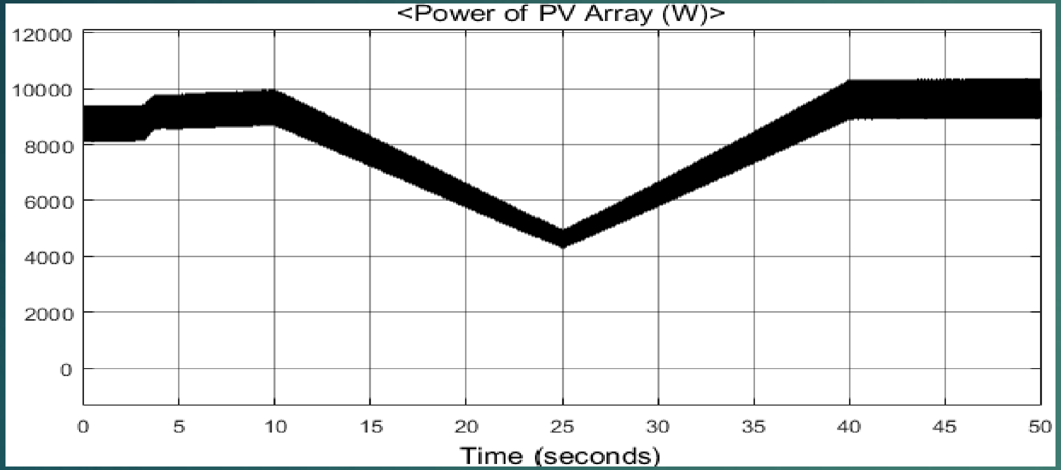
$$L_{ac} = \frac{V_{dc}}{8\Delta I_{ripple.max} f_{sw}} \quad (5.9)$$

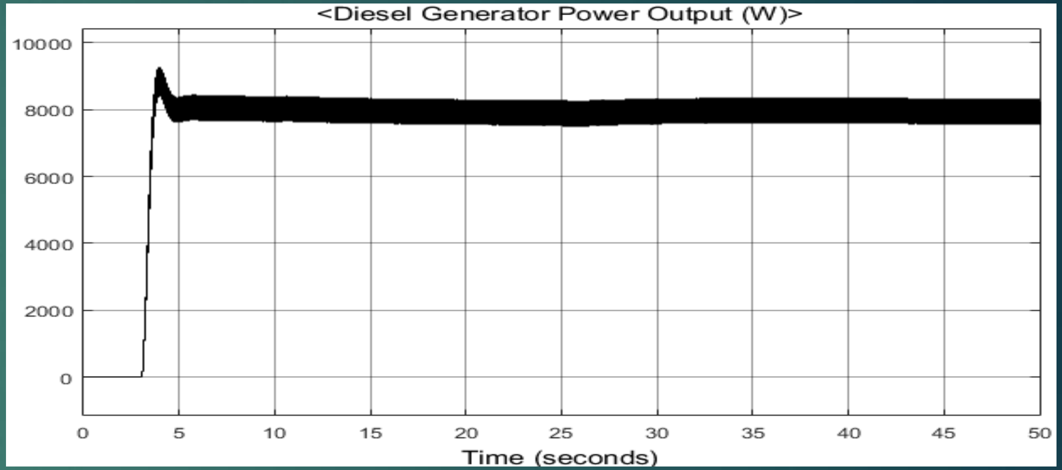
$$C_{ac} = \frac{\alpha P_{rated}}{2\pi f_{line} {V_{rate}}^2} \quad (5.10)$$

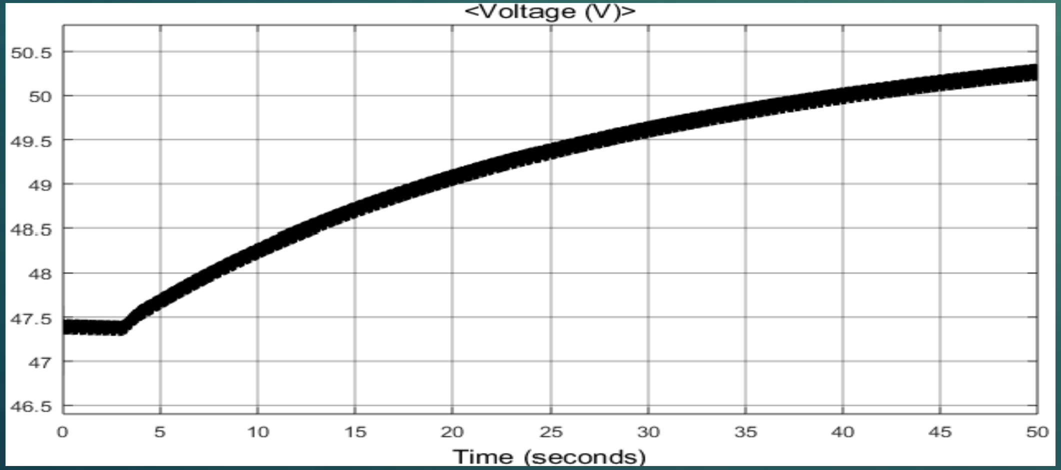
Figure 19 Single-Phase Inverter Model

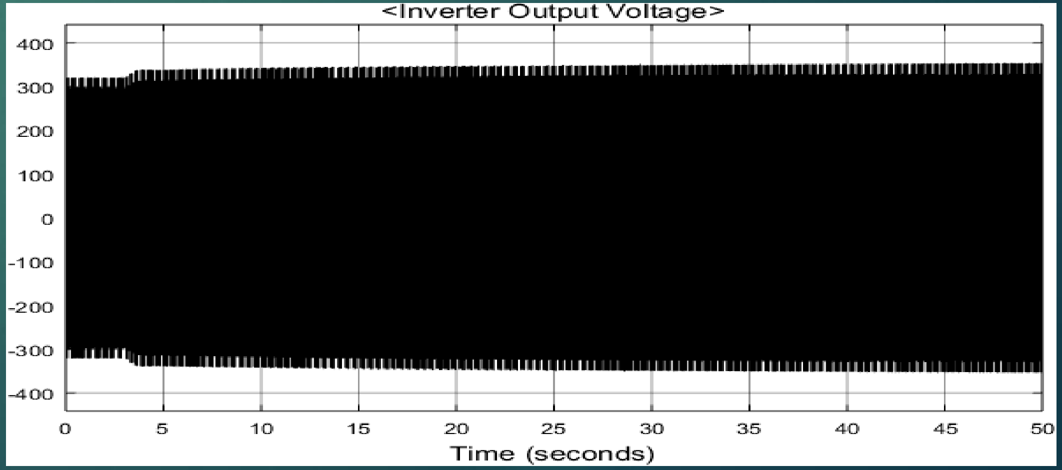
5. Dynamic Modeling and Simulation

- 1st Case Simulation Result



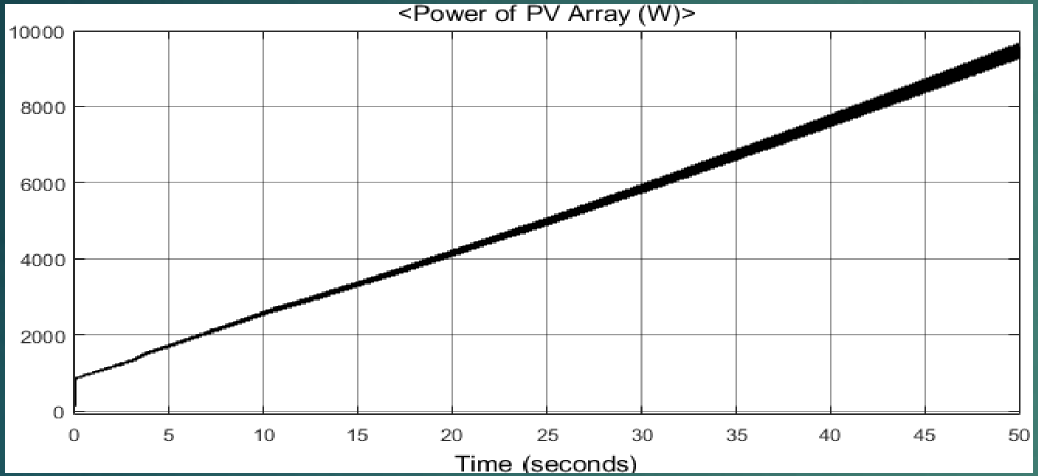


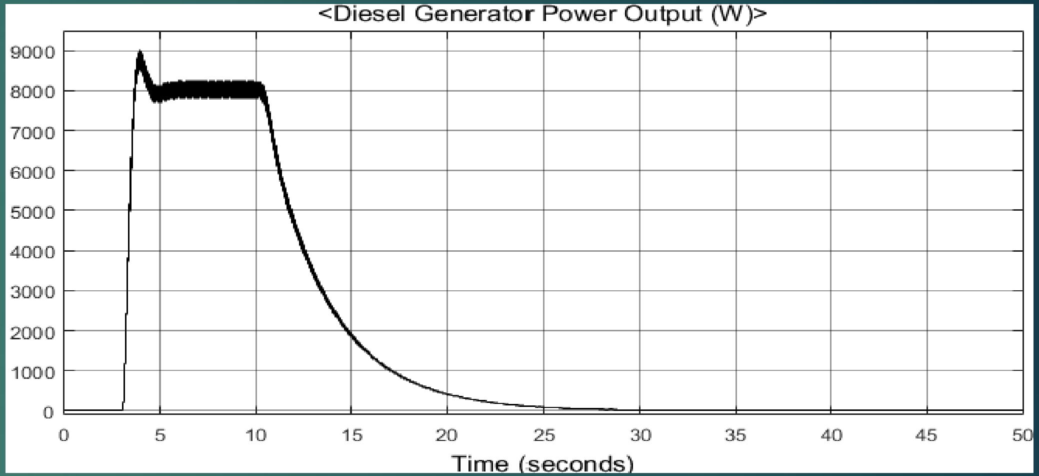


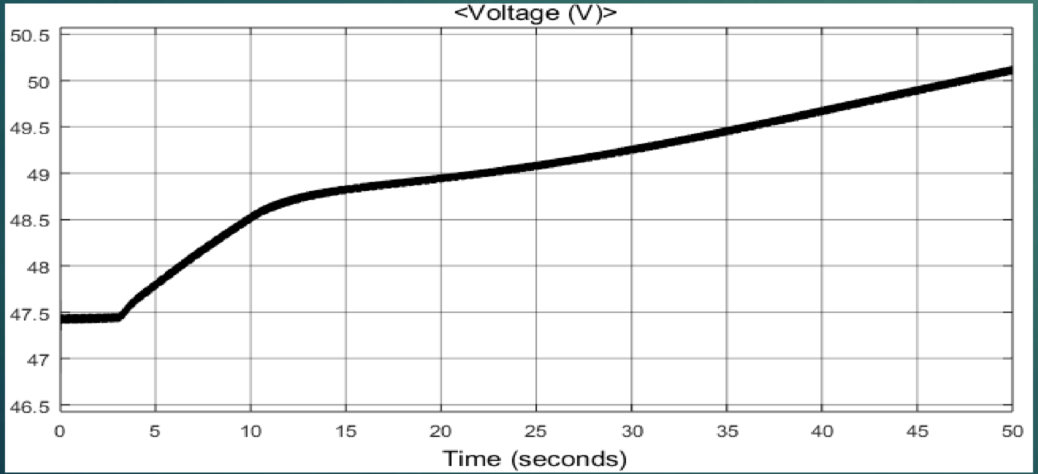


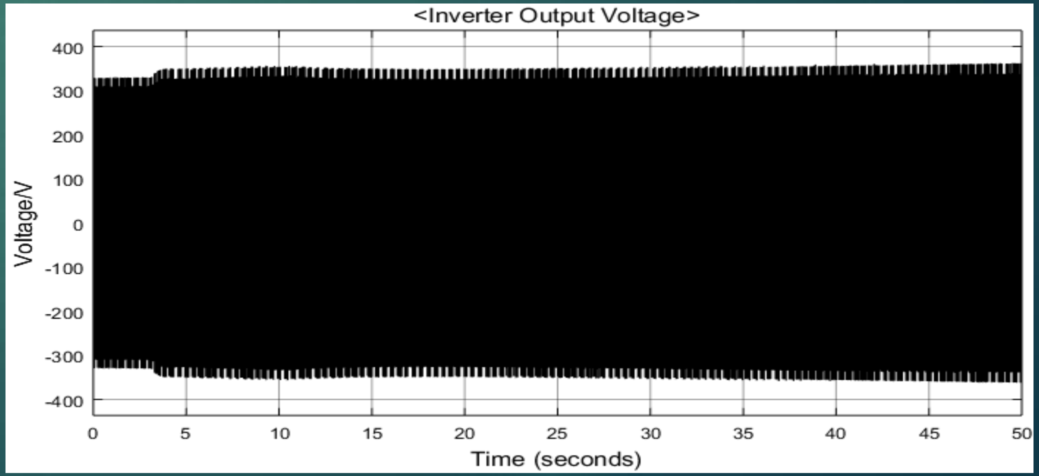
5. Dynamic Modeling and Simulation

- 2nd Case Simulation Result



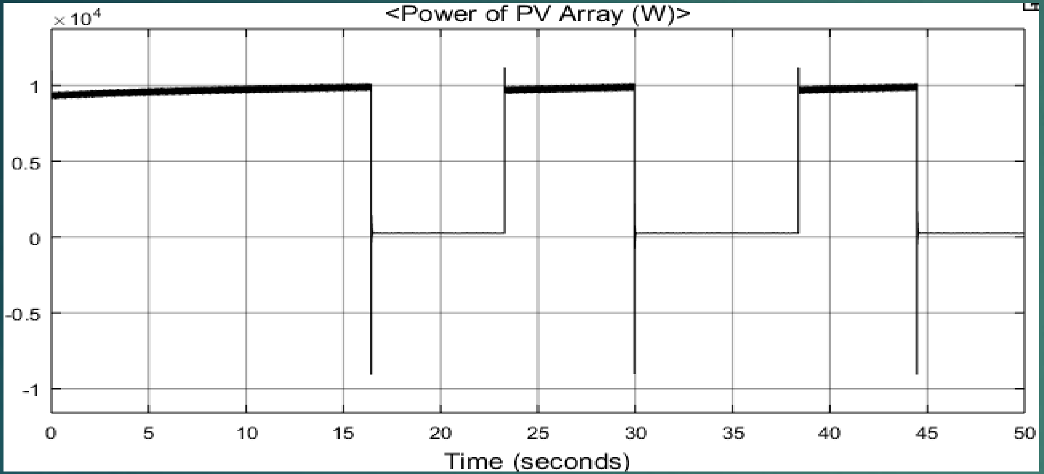


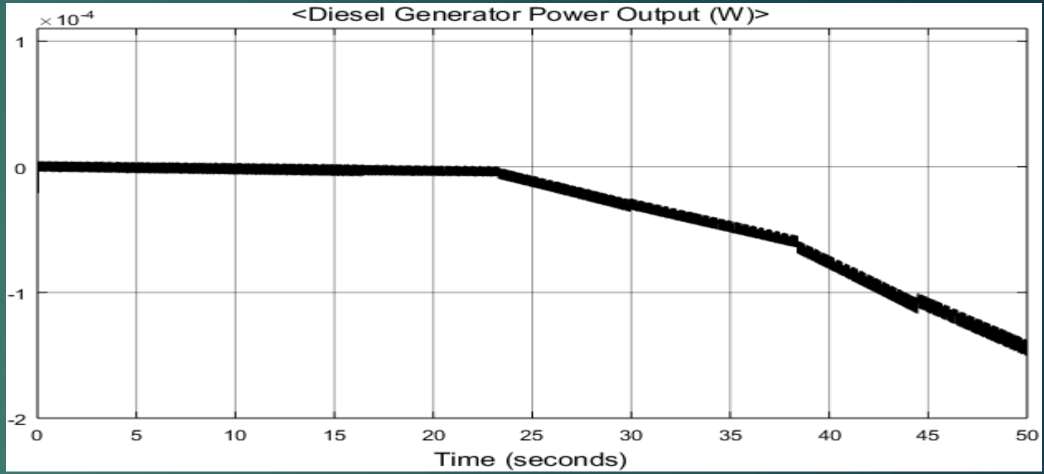


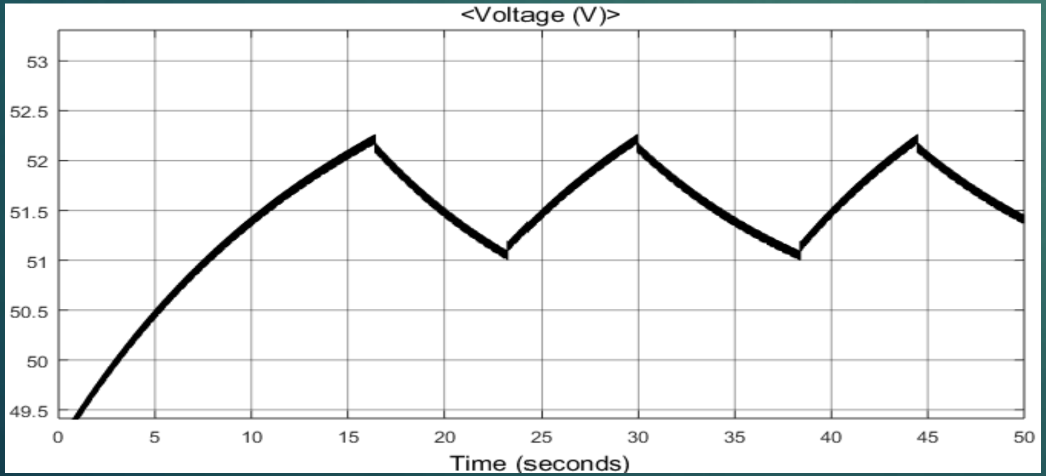


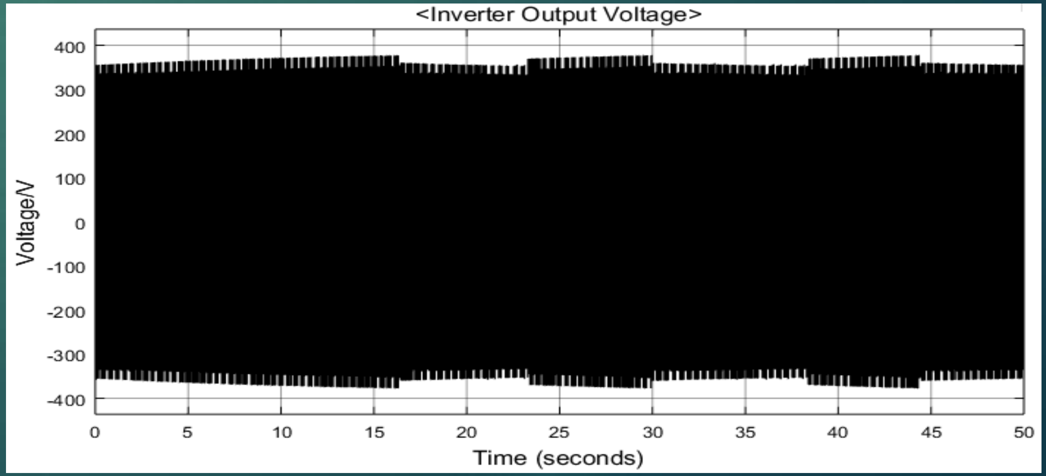
5. Dynamic Modeling and Simulation

- 3rd Case Simulation Result









5. Dynamic Modeling and Simulation

- Problems of the Designed Model

Figure 19 Unstable DC Input Voltage

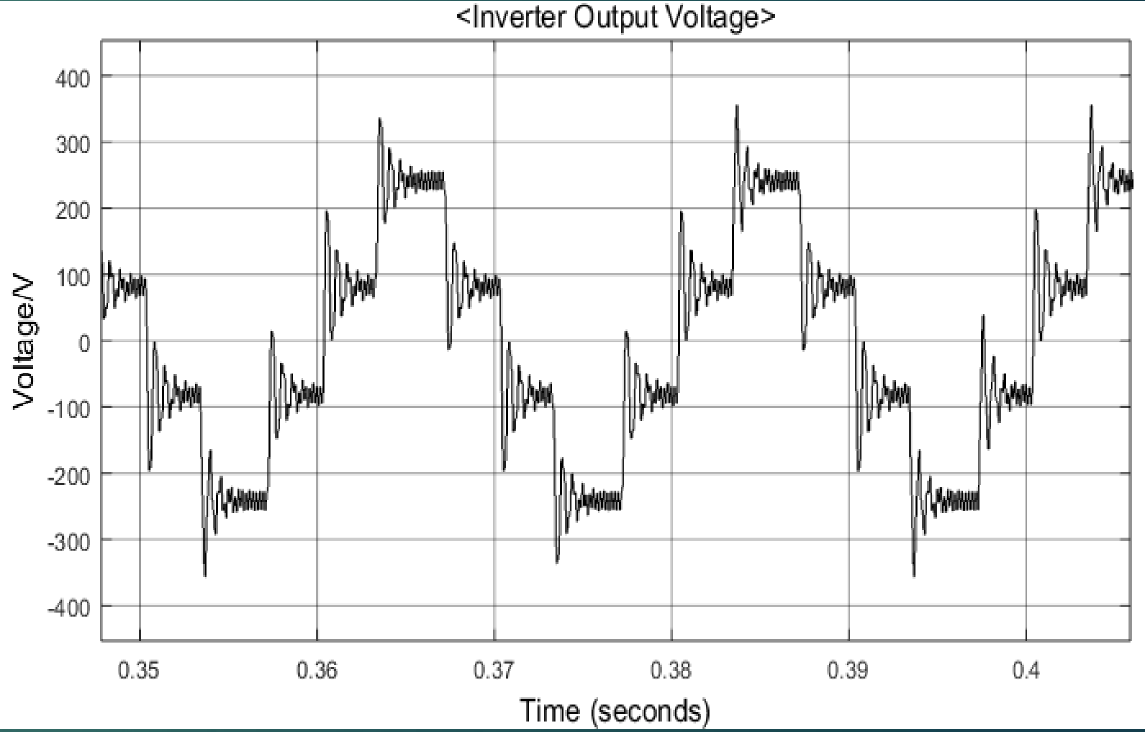
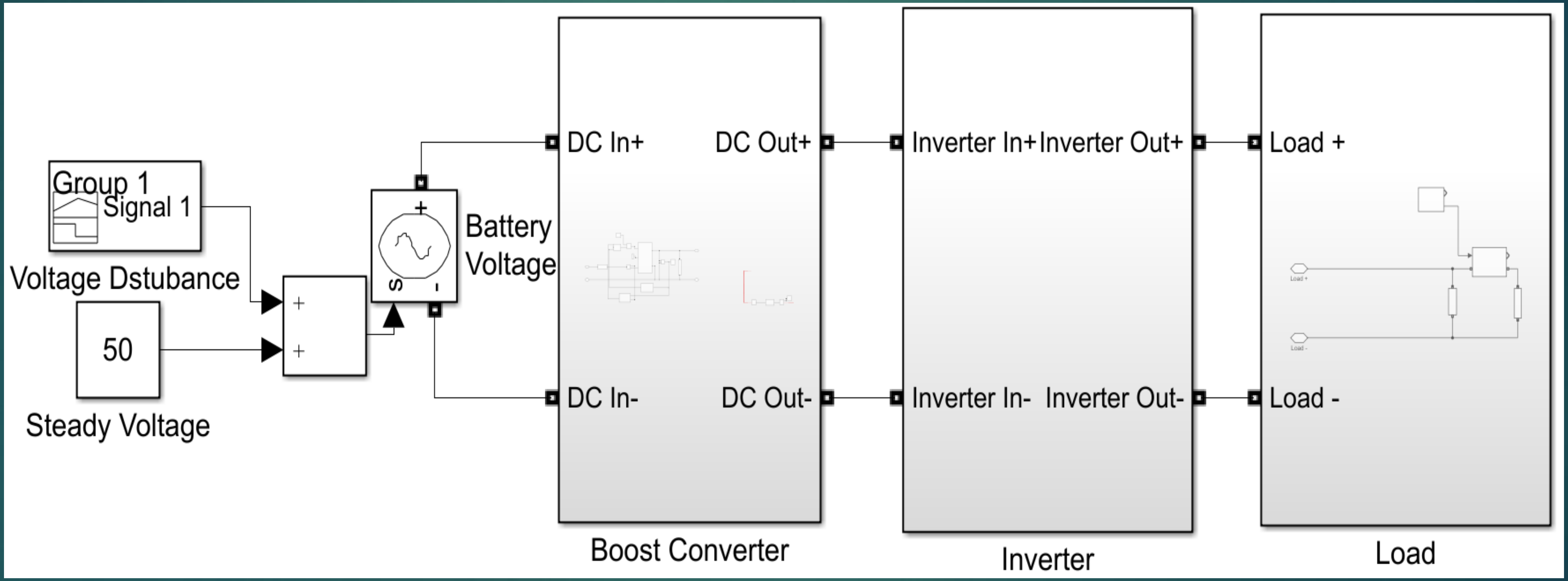


Figure 20 Waveform Distortion of Inverter Output Voltage

5. Dynamic Modeling and Simulation

- DC Voltage Regulator of a Single-Phase Inverter



5. Dynamic Modeling and Simulation

- Mathematic Model and PID+R+CCF Controller of a Single-Phase Inverter

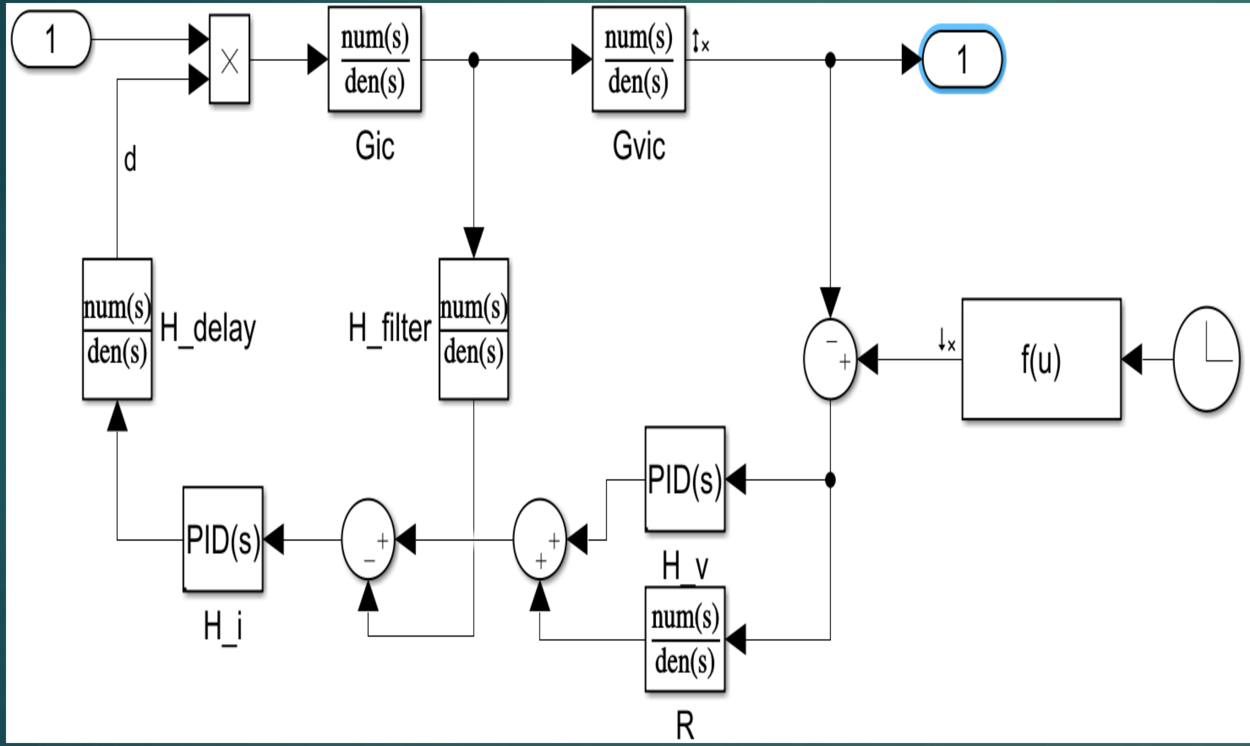


Figure 19 Mathematic Model and PID+R+CCF Controller of Inverter

$$G_{iC} = \frac{sC_{ac}Z_{ac}V_{dc}}{s^2L_{ac}C_{ac}+sL_{ac}+Z_{ac}} \quad (5.11)$$

$$G_{viC} = \frac{1}{sC_{ac}} \quad (5.12)$$

$$H_{delay} = \frac{1-0.5T_{delay}s+\left(\frac{T_{delay}}{12}\right)^2 s^2}{1+0.5T_{delay}s+\left(\frac{T_{delay}}{12}\right)^2 s^2} \quad (5.13)$$

$$H_{filter} = \frac{{\omega_0}^2}{1+2\zeta\omega_0+{\omega_0}^2} \quad (5.14)$$

5. Dynamic Modeling and Simulation

- Calculations of Boost Converter

$$V_{o\_ripple\_ESR} = I_{in} \cdot R_{ESR} \quad (5.15)$$

$$C_{min\_ripple} = \frac{I_{in}}{V_{o\_ripple\_C} \cdot f_{sw}} \left(1 - \frac{V_{in}}{V_o}\right) \quad (5.16)$$

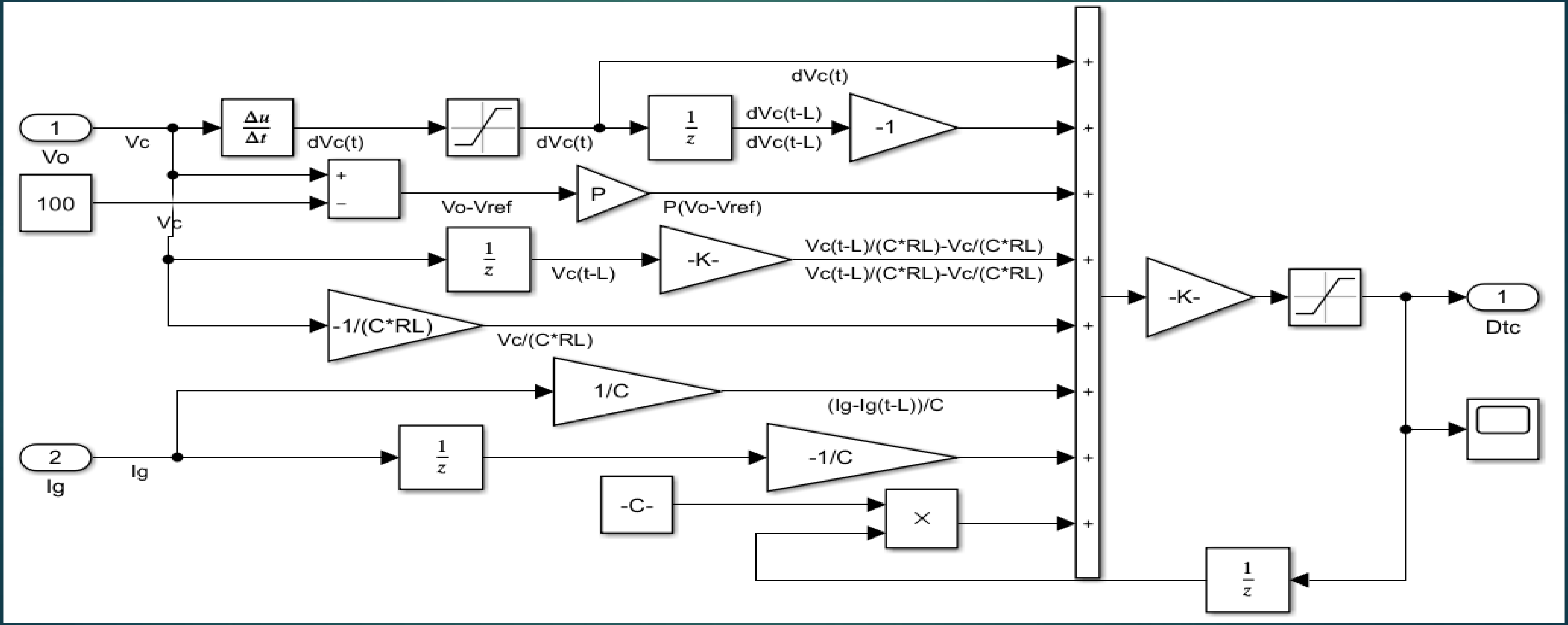
$$R_{DCR\_max} = \frac{0.3 P_{total\_loss}}{{I_{in}}^2} \quad (5.17)$$

$$P_{total\_loss} = P_{total} \left(\frac{1}{\eta} - 1\right) \quad (5.18)$$

$$L_{max} = C \cdot \left[R_{max} \cdot V_{in\_max} / (10 \cdot V_o)\right]^2 \quad (5.19)$$

5. Dynamic Modeling and Simulation

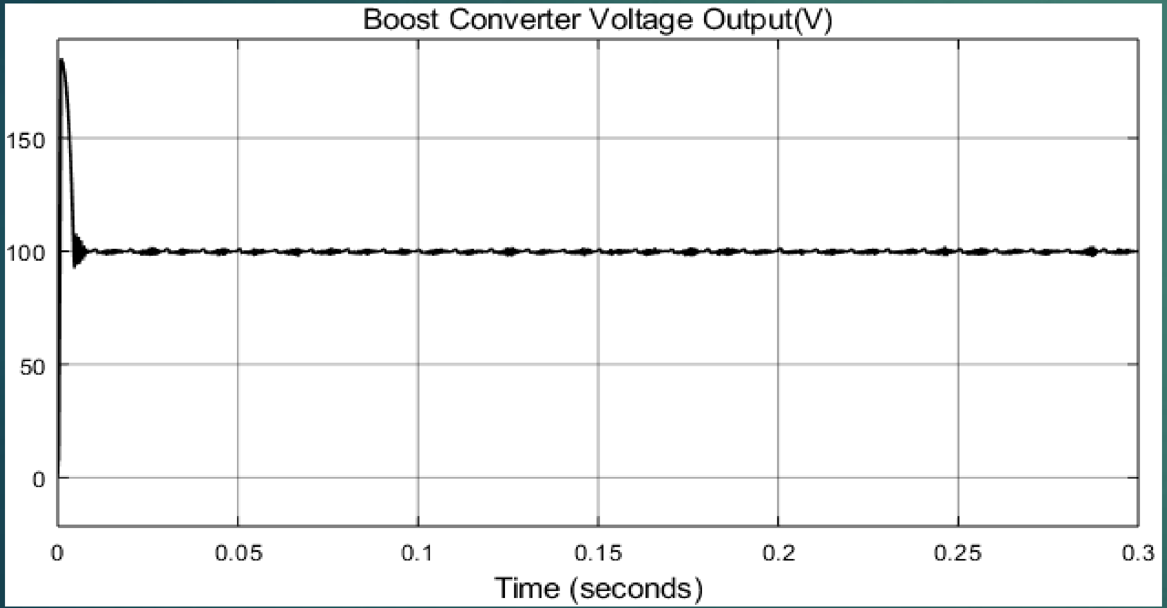
- Time-Delayed Controller of Boost Converter

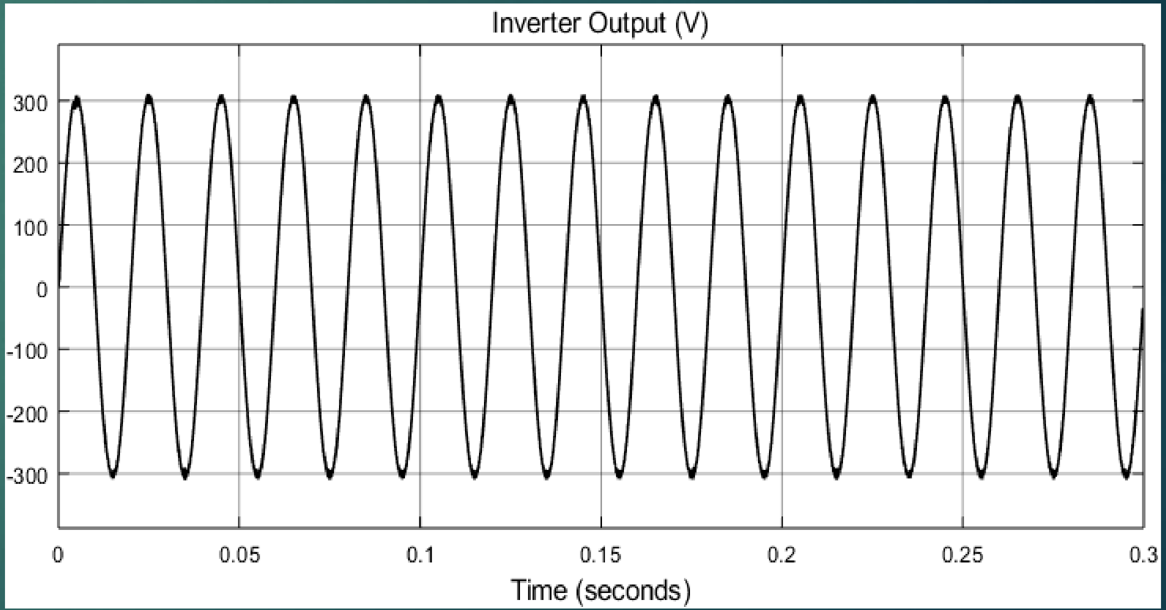


5. Dynamic Modeling and Simulation

- Simulation Results

- Maximum Load with Transient Voltage Disturbance

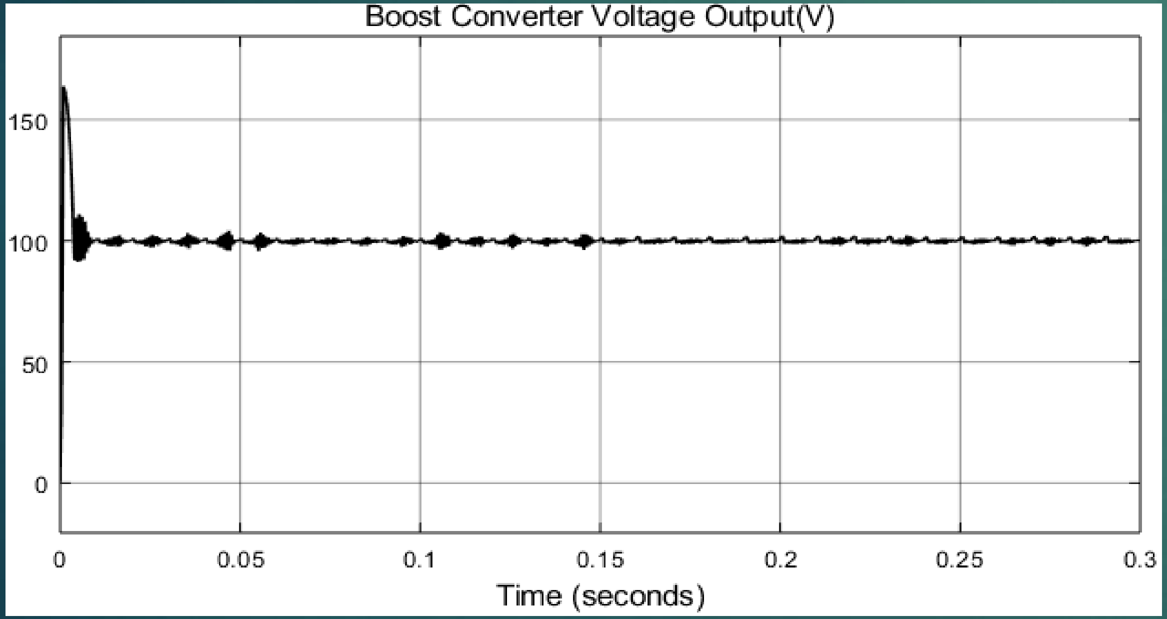


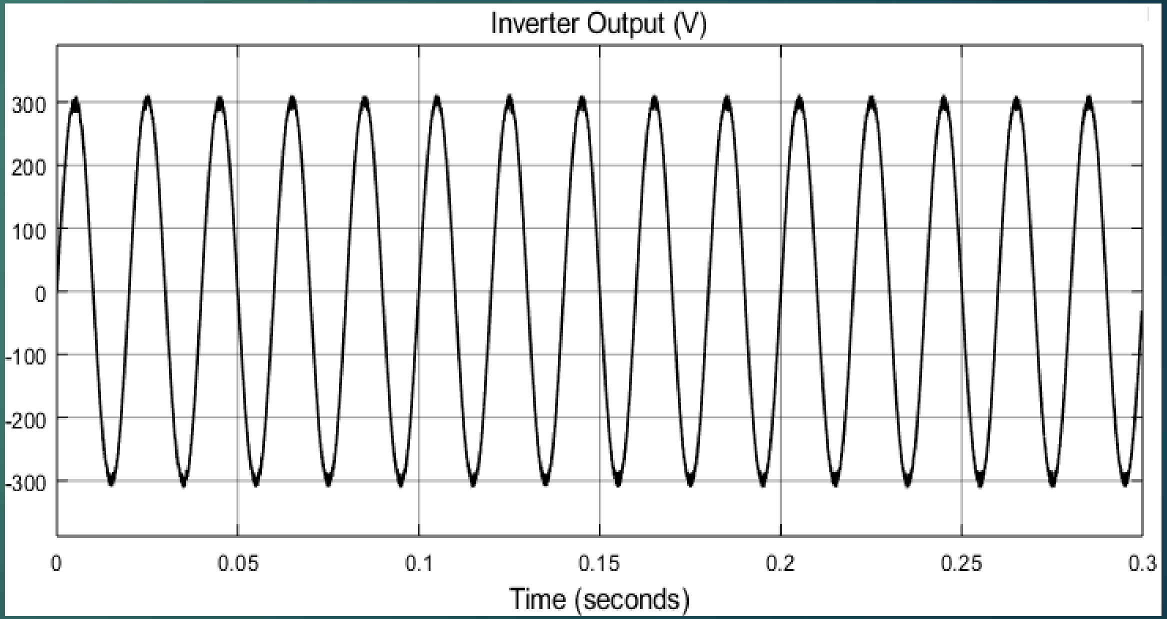


5. Dynamic Modeling and Simulation

- Simulation Results

- Maximum Load with Low-High Voltage Transition

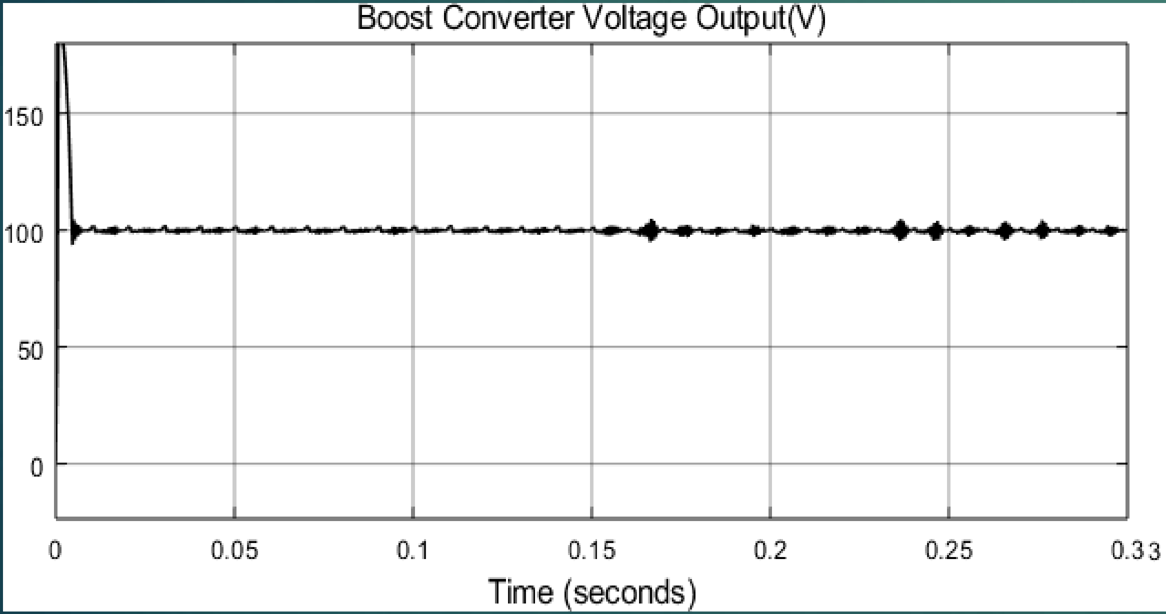


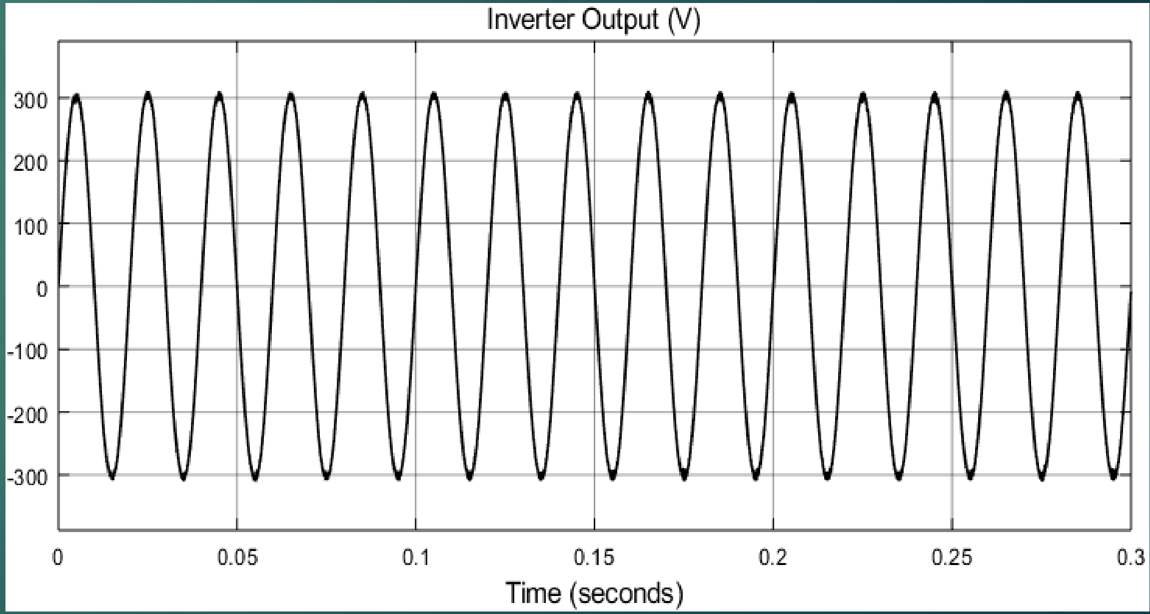


5. Dynamic Modeling and Simulation

- Simulation Results

- Maximum Load with High-Low Voltage Transition

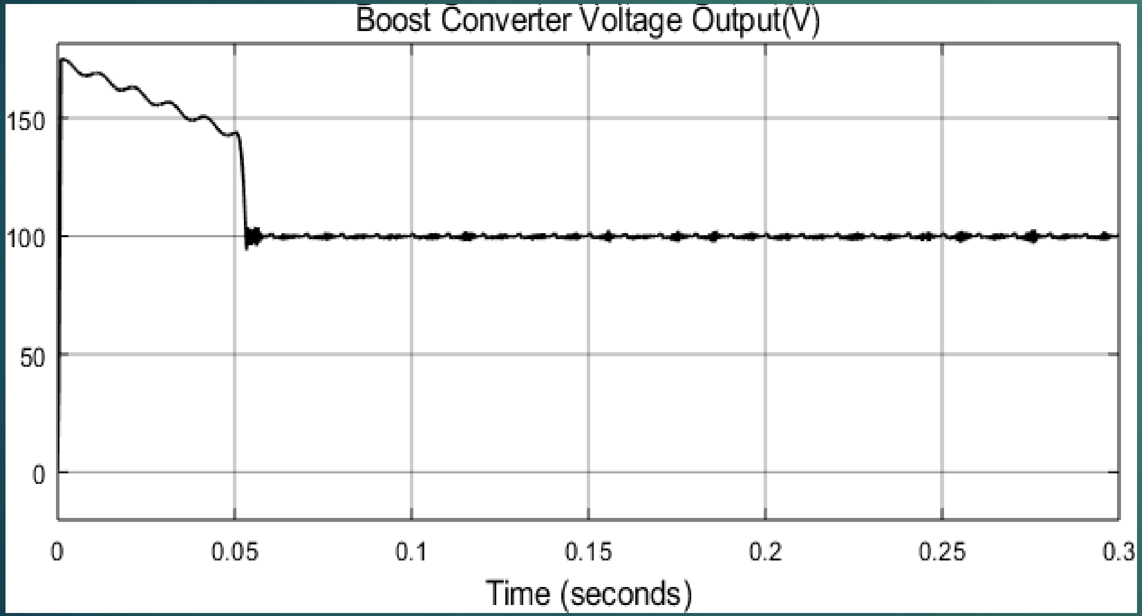


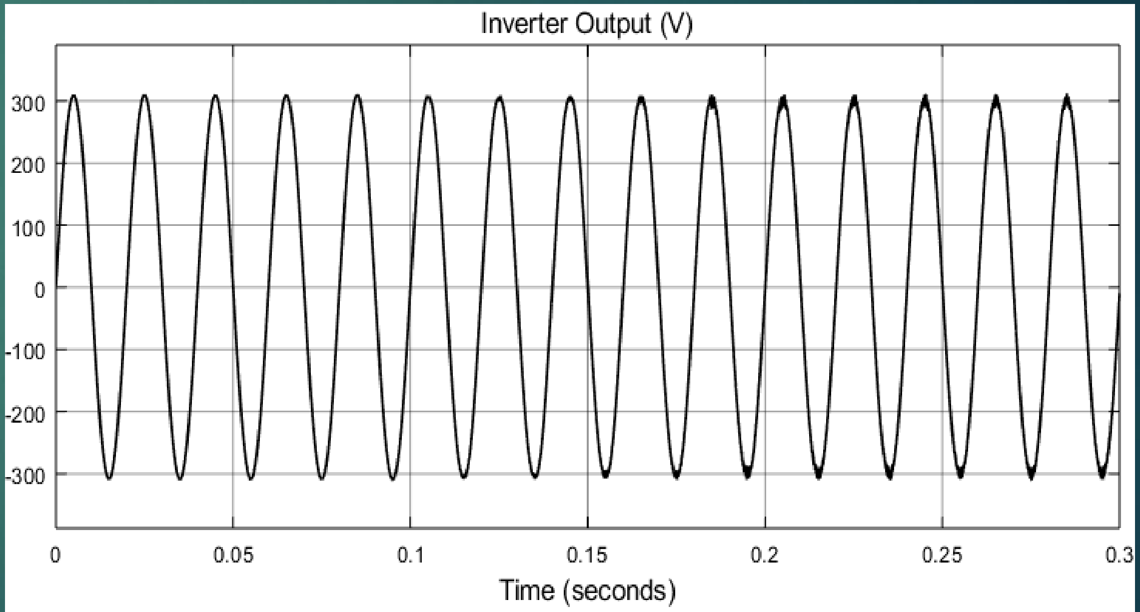


5. Dynamic Modeling and Simulation

- Simulation Results

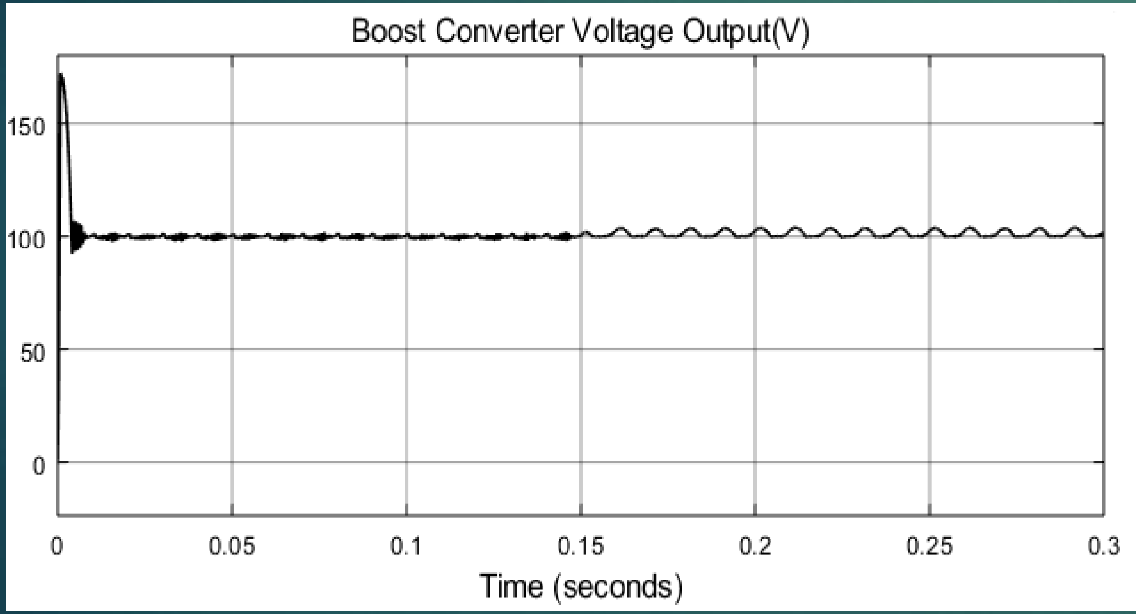
- Light-Heavy Load Transition

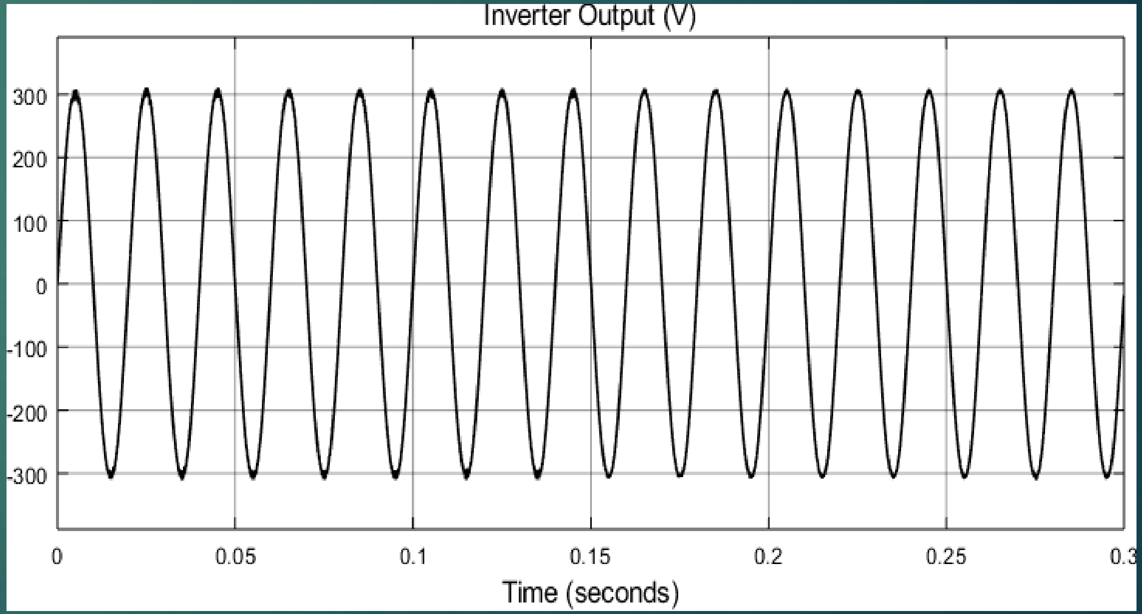




5. Dynamic Modeling and Simulation

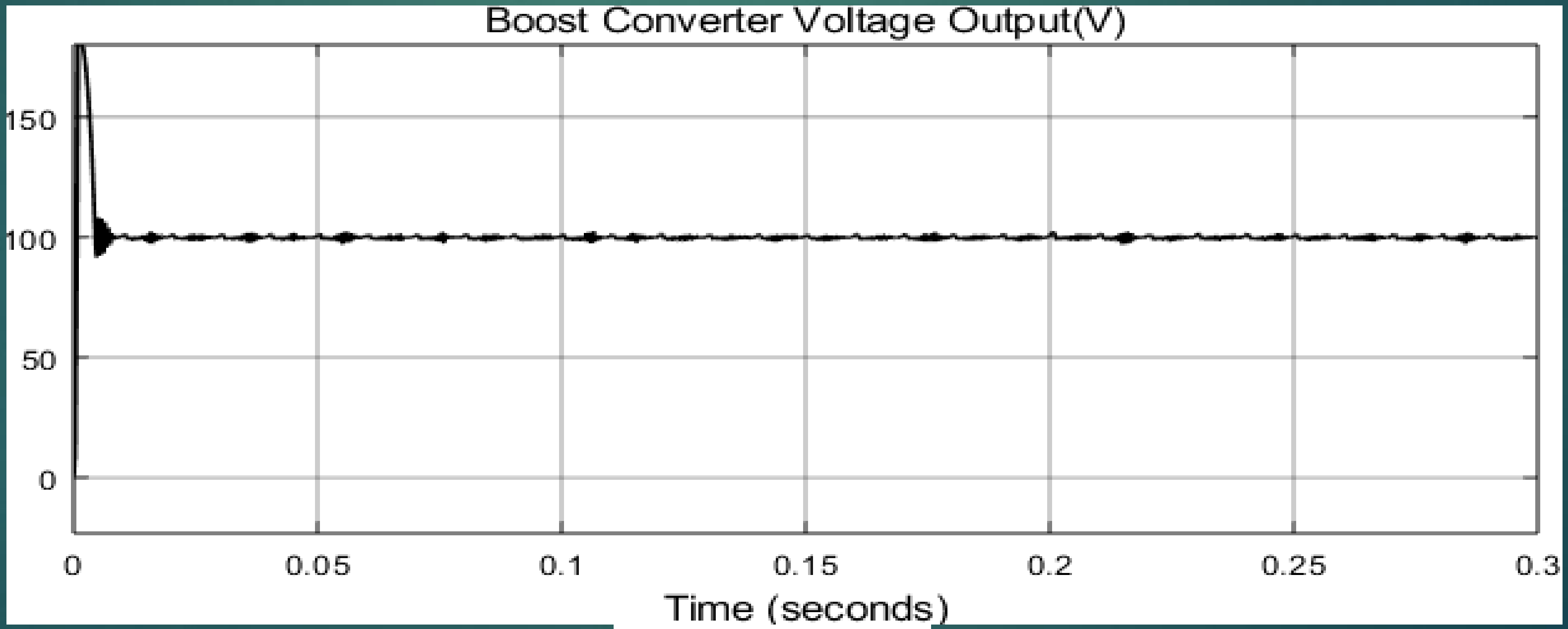
- Simulation Results
- Heavy-Light Load Transition





5. Dynamic Modeling and Simulation

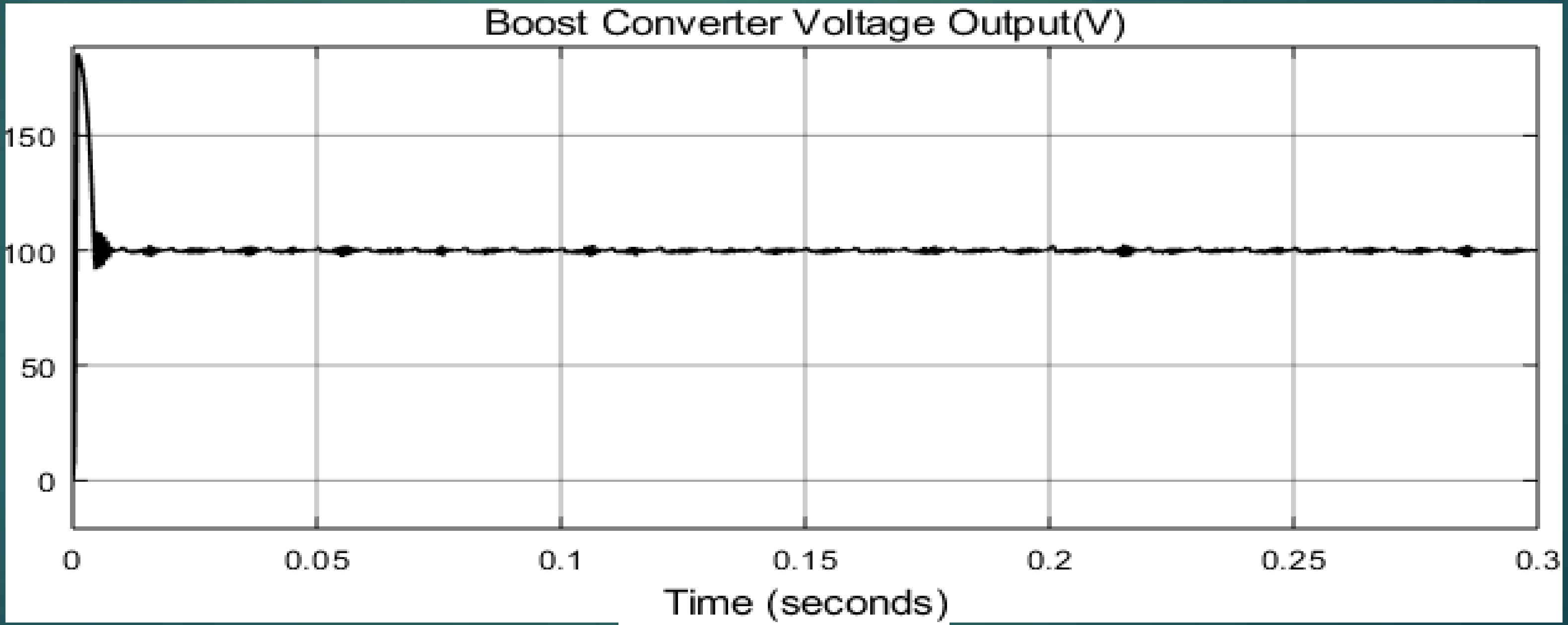
- Simulation Results
- Tuning of Time Delayed Controller
- Tuning of I_{ra}, $R_{L.ra} = 4R_L$



$I_{ra} = 42.182$

5. Dynamic Modeling and Simulation

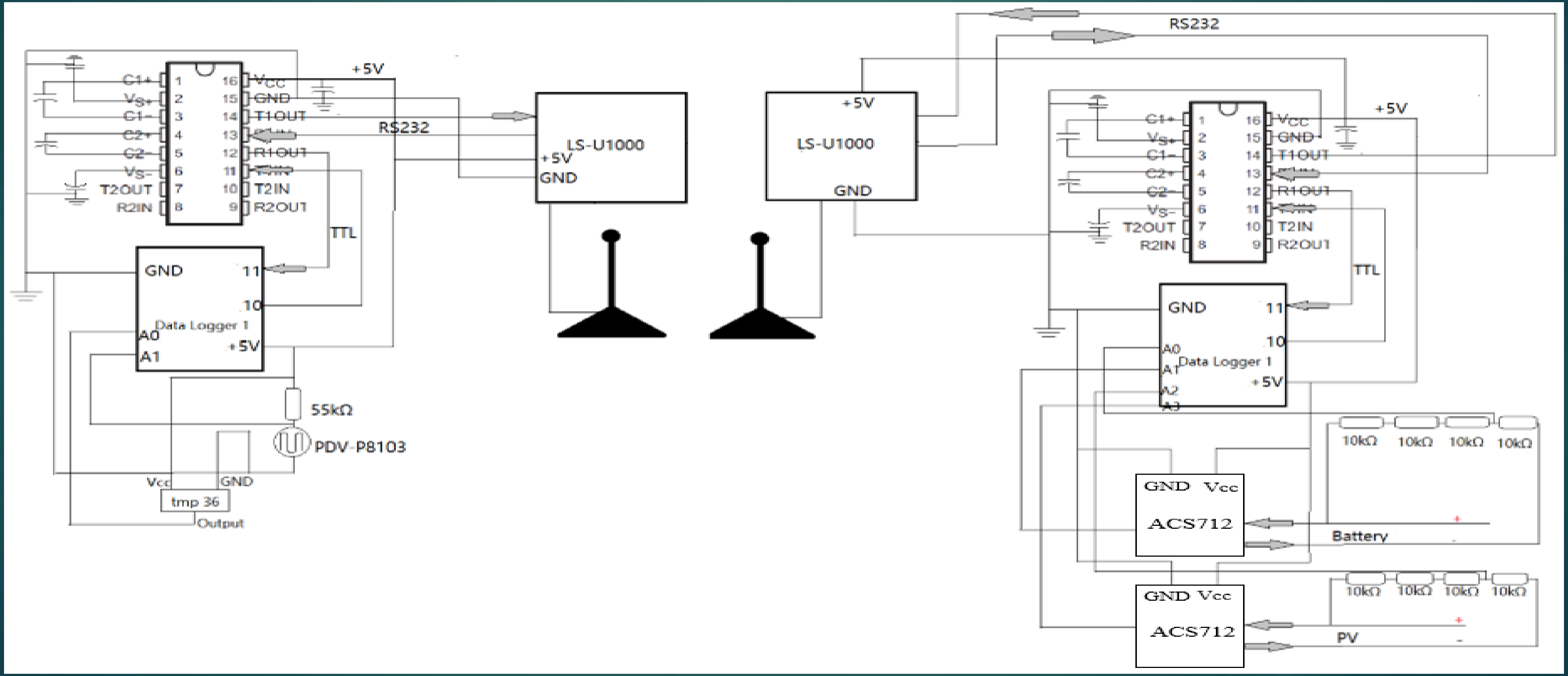
- Simulation Results
- Tuning of Time Delayed Controller
- Tuning of $R_{L.ra}$, $I_{ra} = 42.182$



$R_{L.ra} = 4R_L$

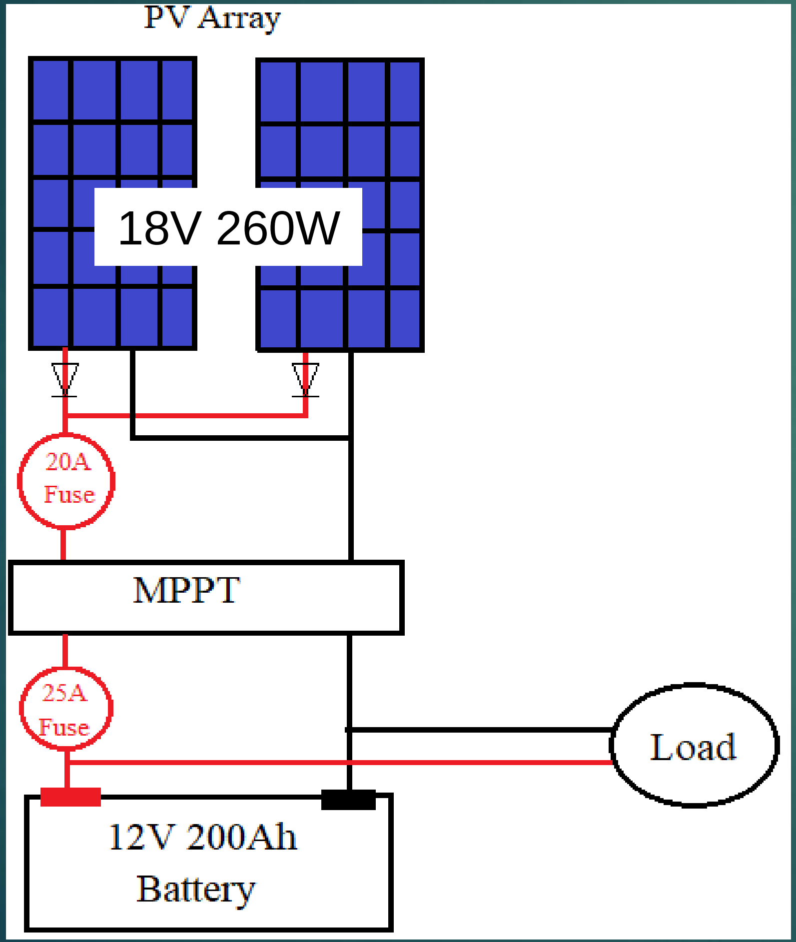
6. Data Logging and Visualization System

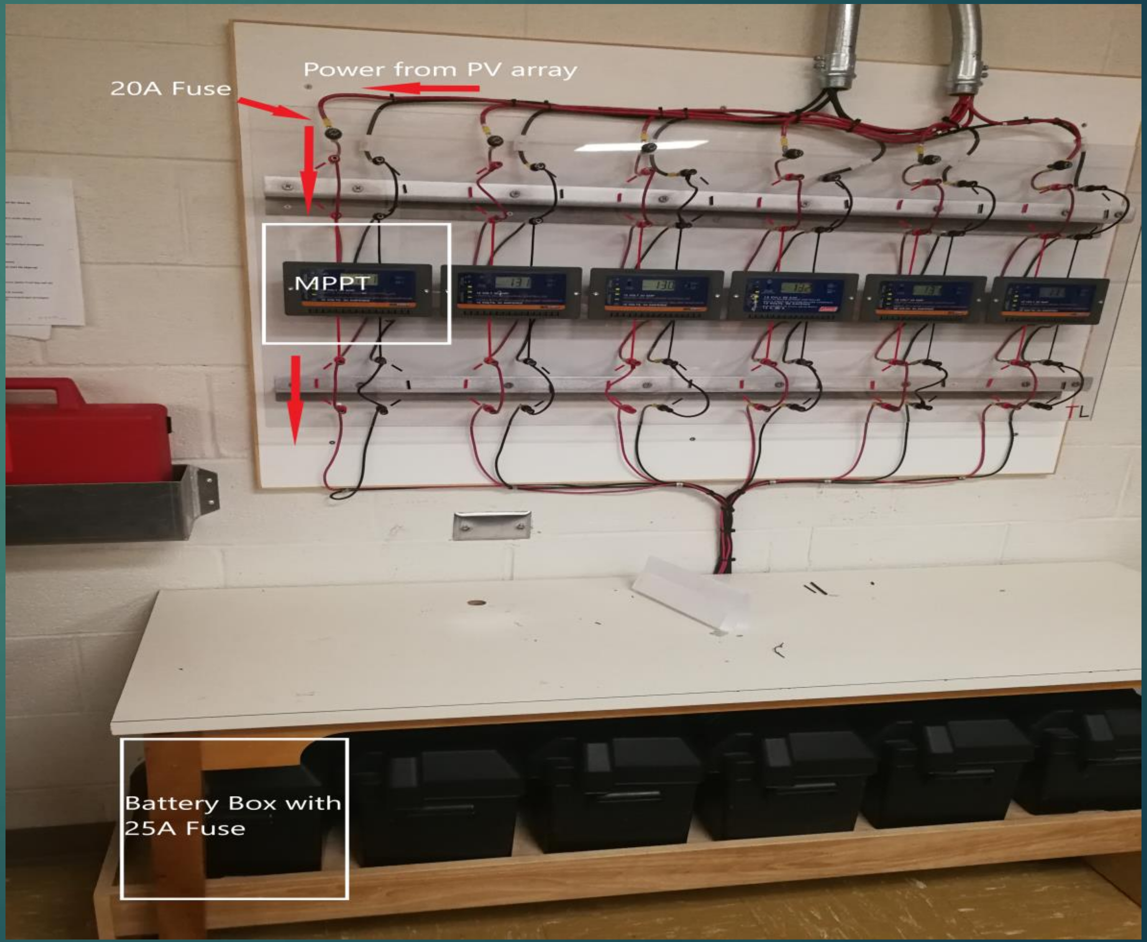
- Overall System Schematic, System Setup and Detailed Wiring Diagram



6. Data Logging and Visualization System

- PV System





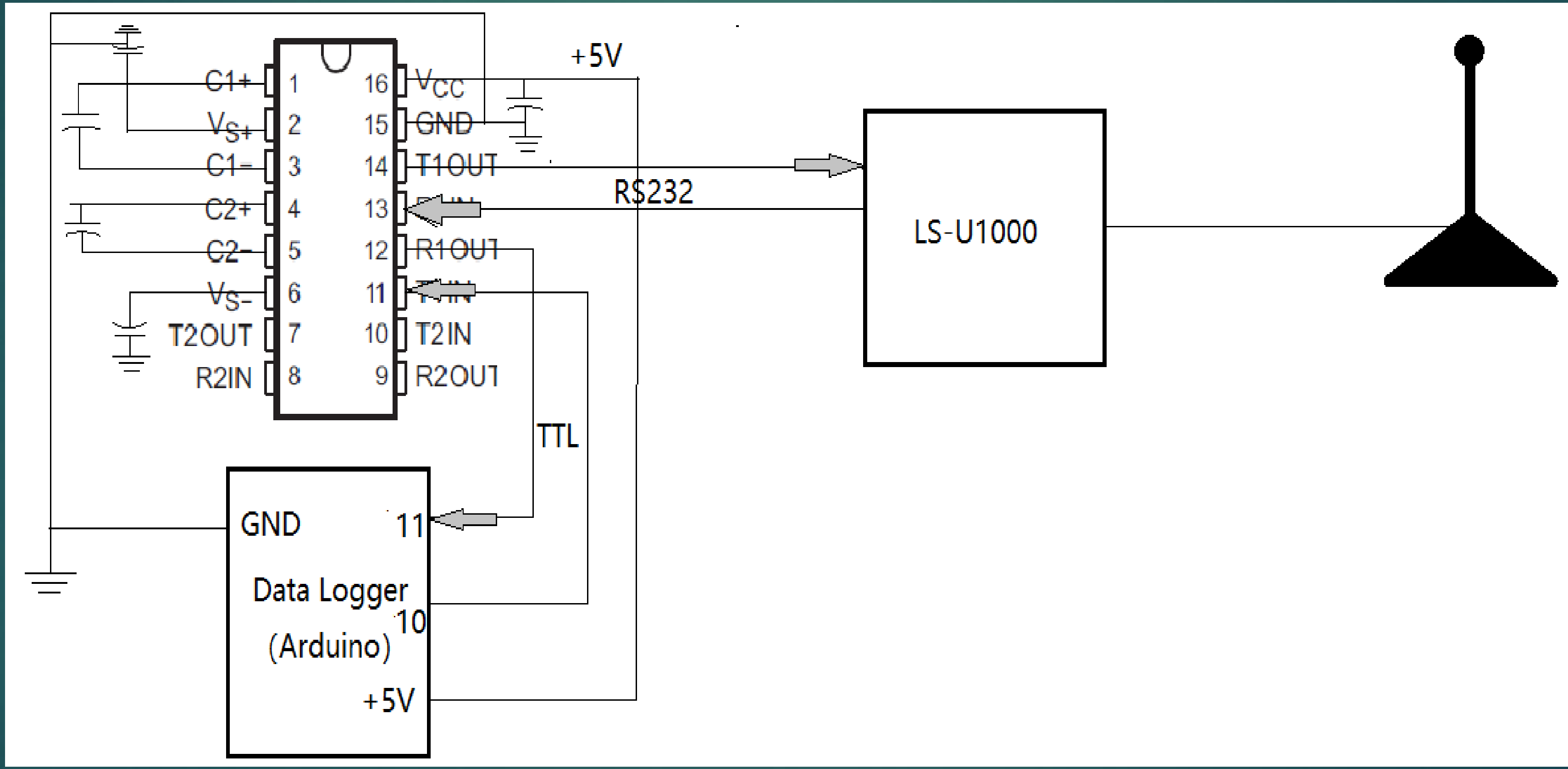
6. Data Logging and Visualization System

- Sensors and Real-Time Measurement Calculation

Type of Sensor	Measurement Calculation
PV Current	$I_{real} = \frac{Data}{38.51} - 13.32\ (A)$
PV Voltage	$V_{real} = Data * \frac{Ratio}{51.15}\ (V)$
Battery Current	$I_{real} = \frac{Data}{38.51} - 13.32\ (A)$
Battery Voltage	$V_{real} = Data * \frac{Ratio}{31.19}\ (V)$
Temperature	$T = Data/1.945 - 50$
Solar Radiation	$Ra = 0.0079 * 10^{(2.5311 - lg^{(55.7 * data/(1170.31 - data))})}$

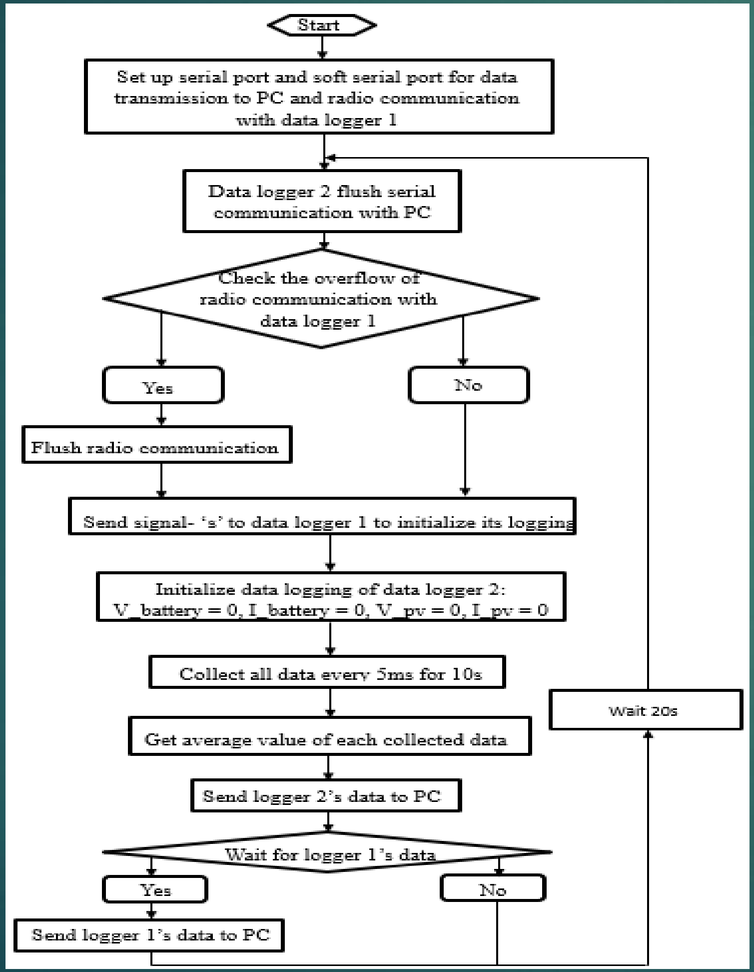
6. Data Logging and Visualization System

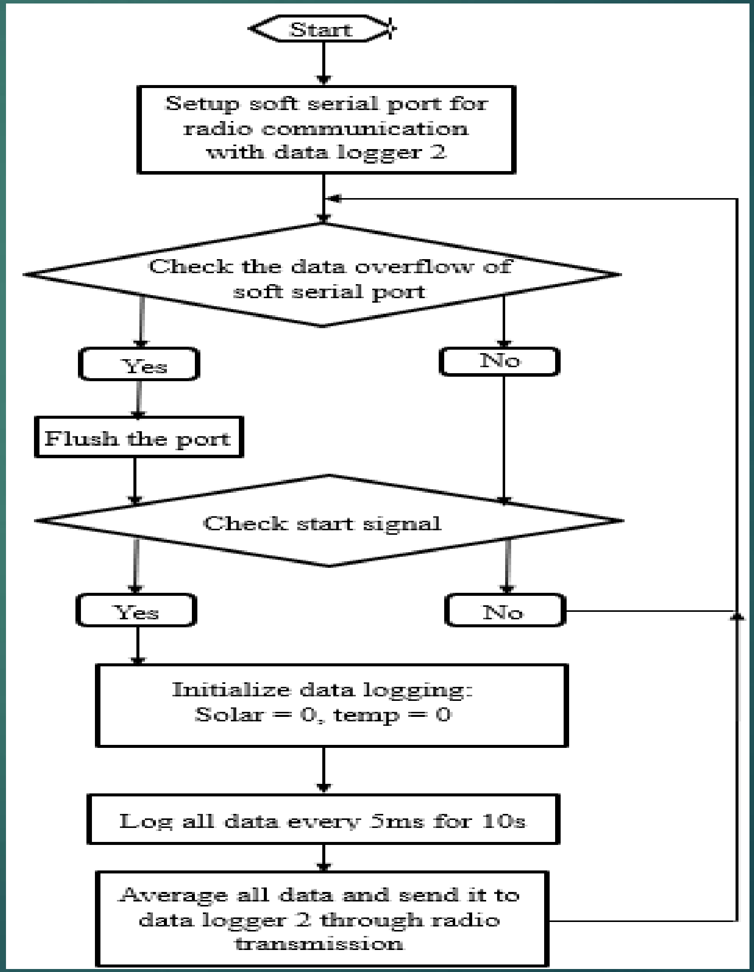
- Radio Communication System



6. Data Logging and Visualization System

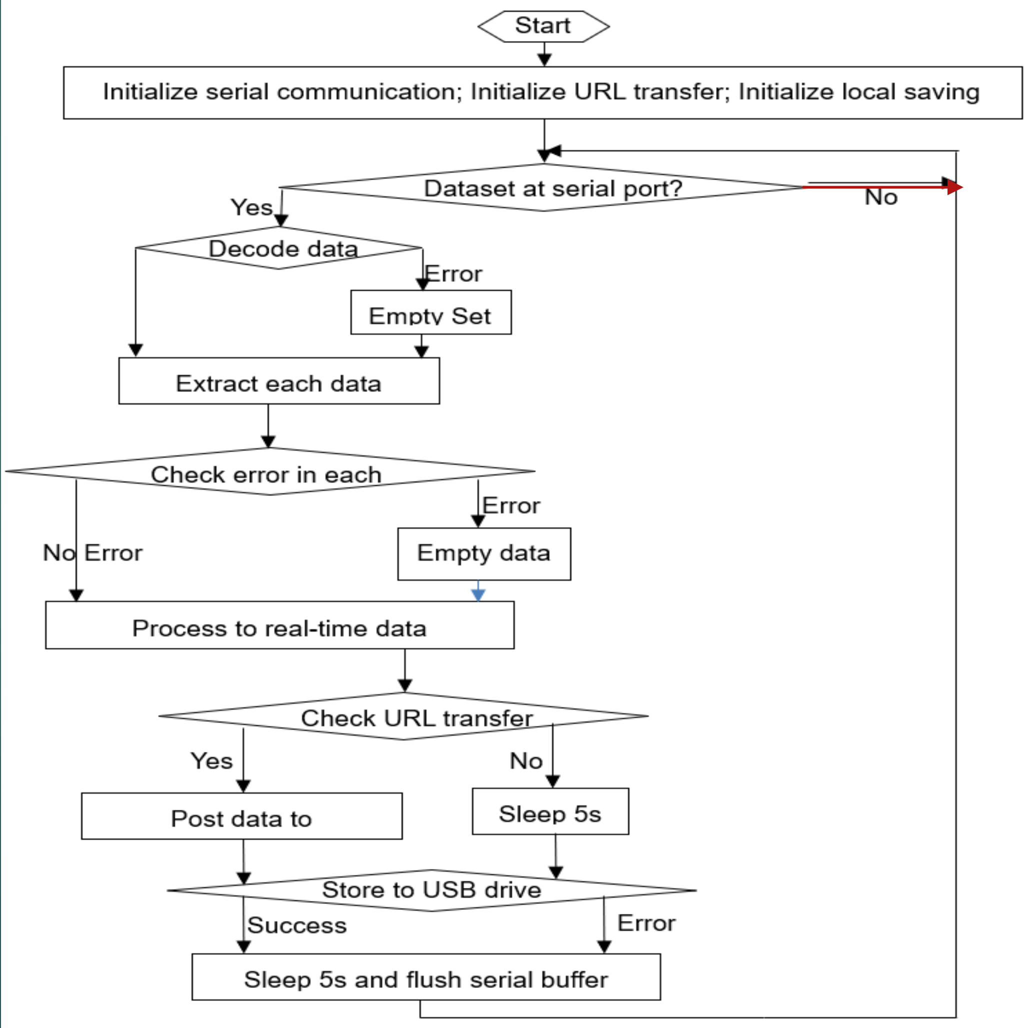
- Programs on Data Loggers (Arduino Boards)





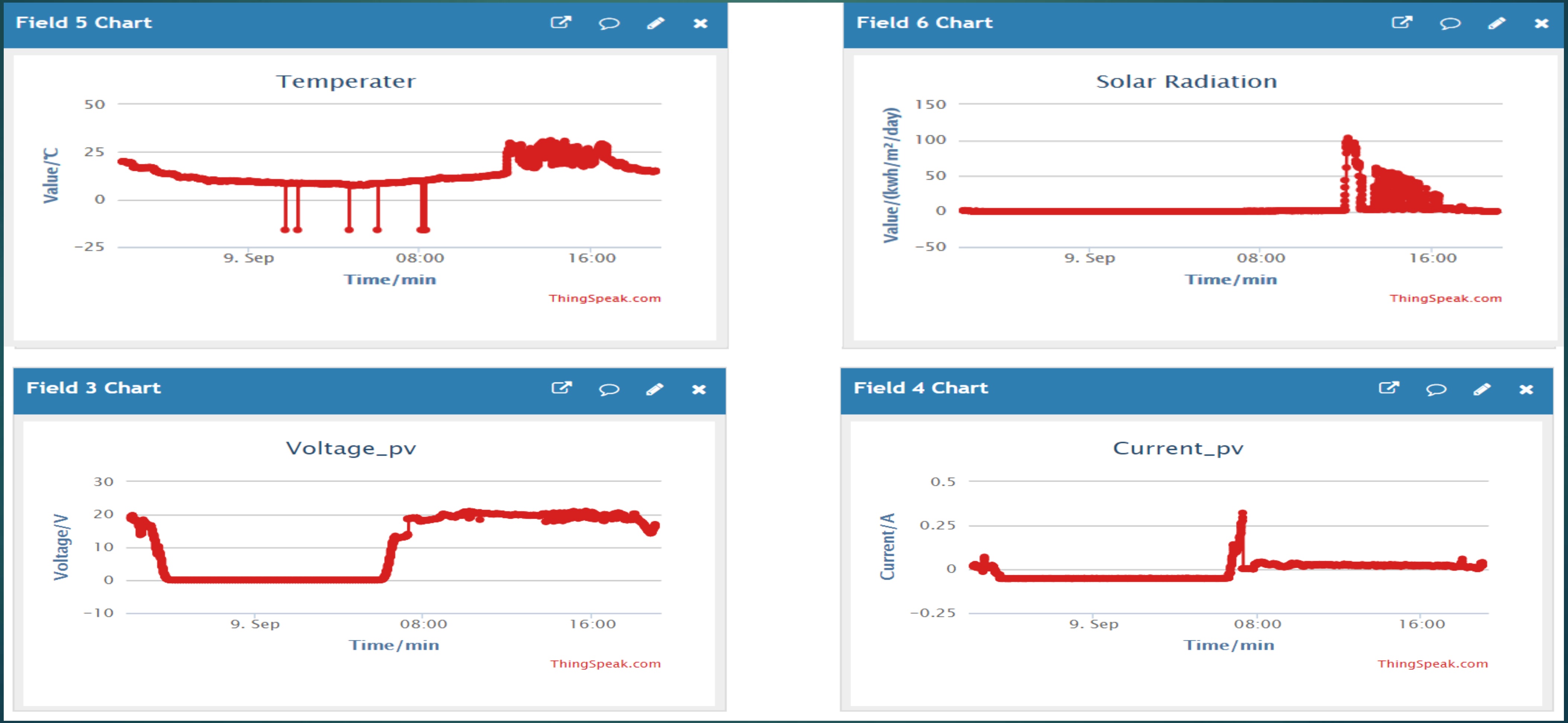
6. Data Logging and Visualization System

- Python Program on PC



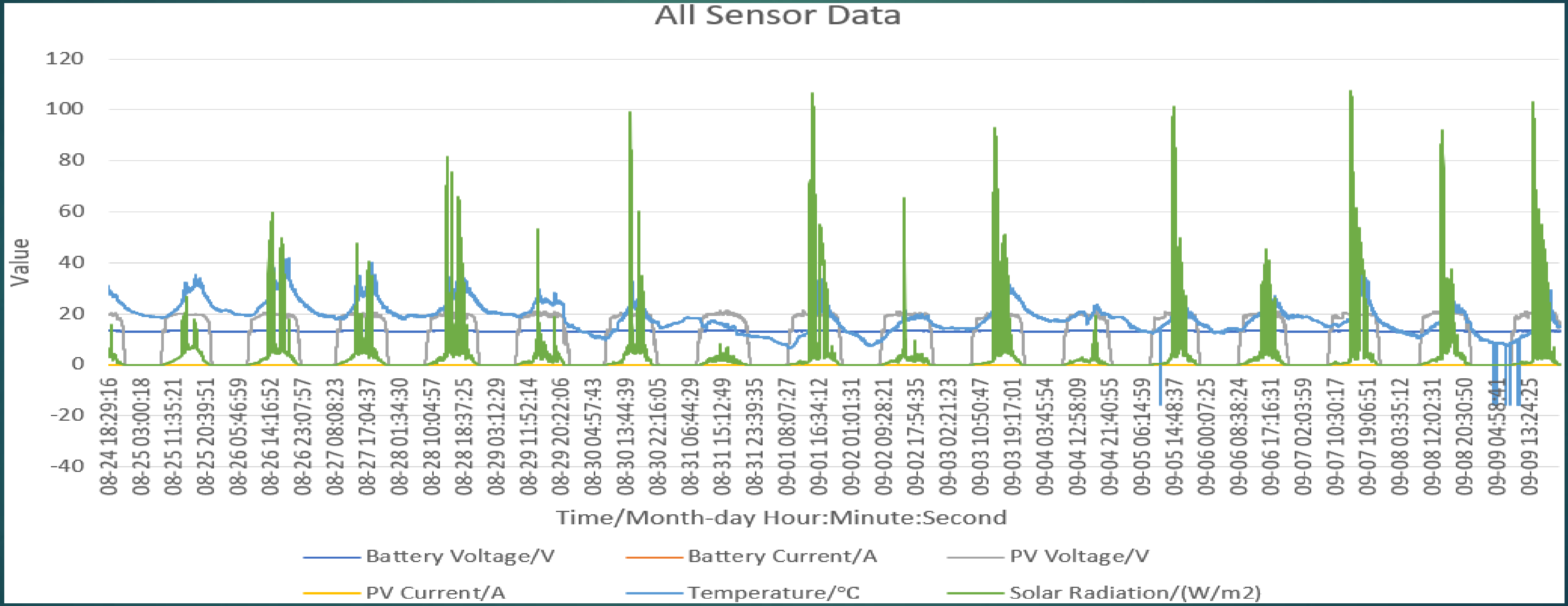
6. Data Logging and Visualization System

- Data Visualization



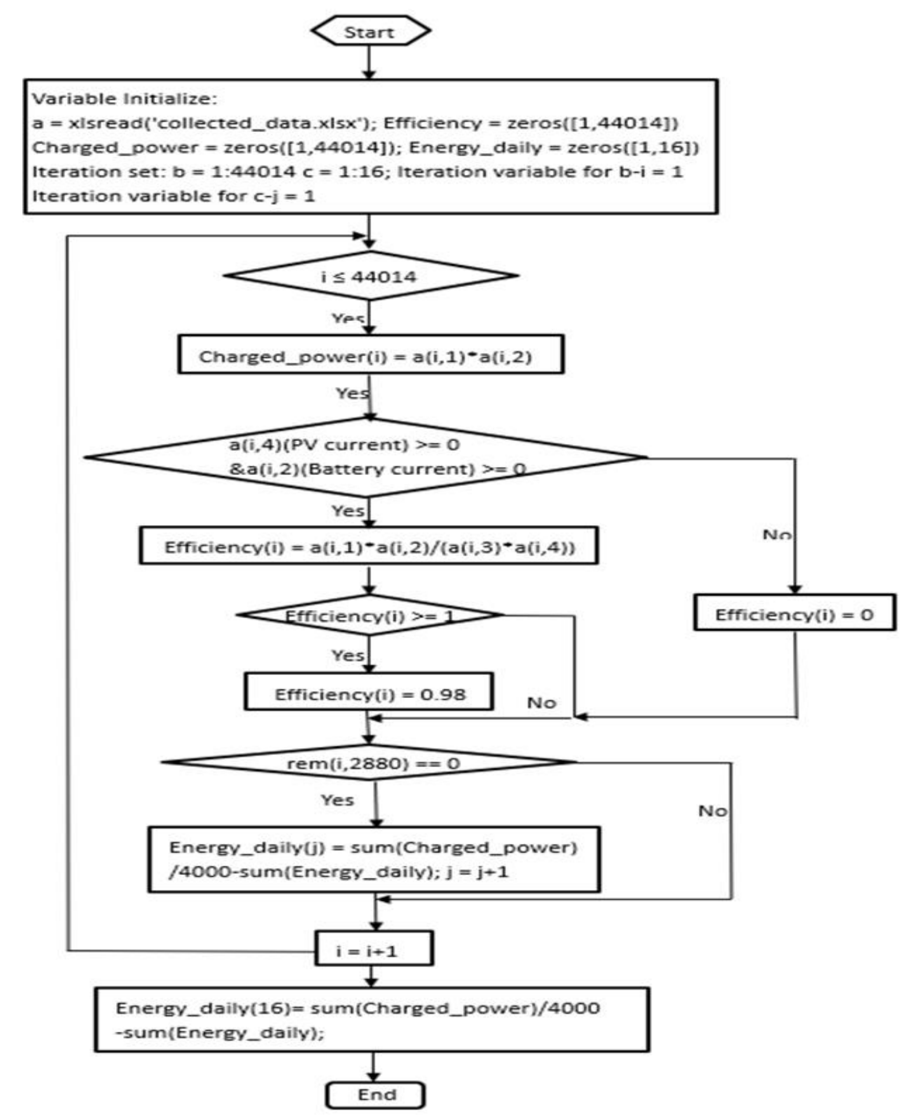
6. Data Logging and Visualization System

- Data Visualization



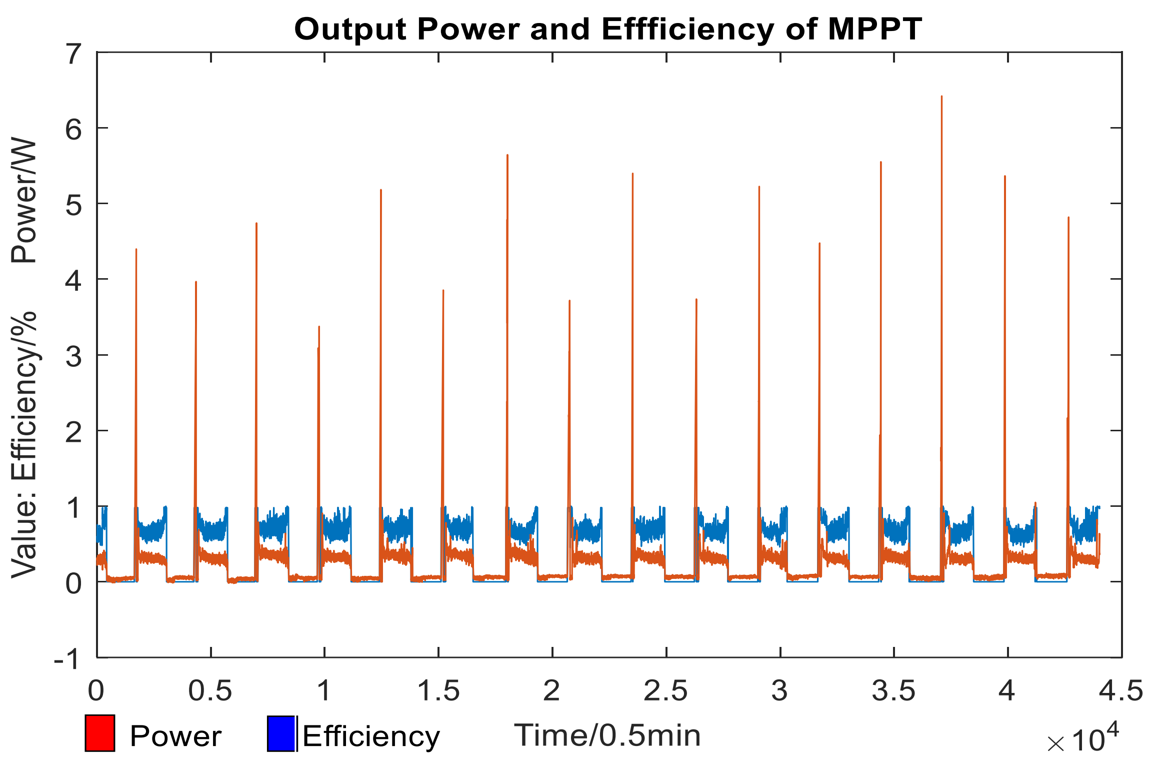
6. Data Logging and Visualization System

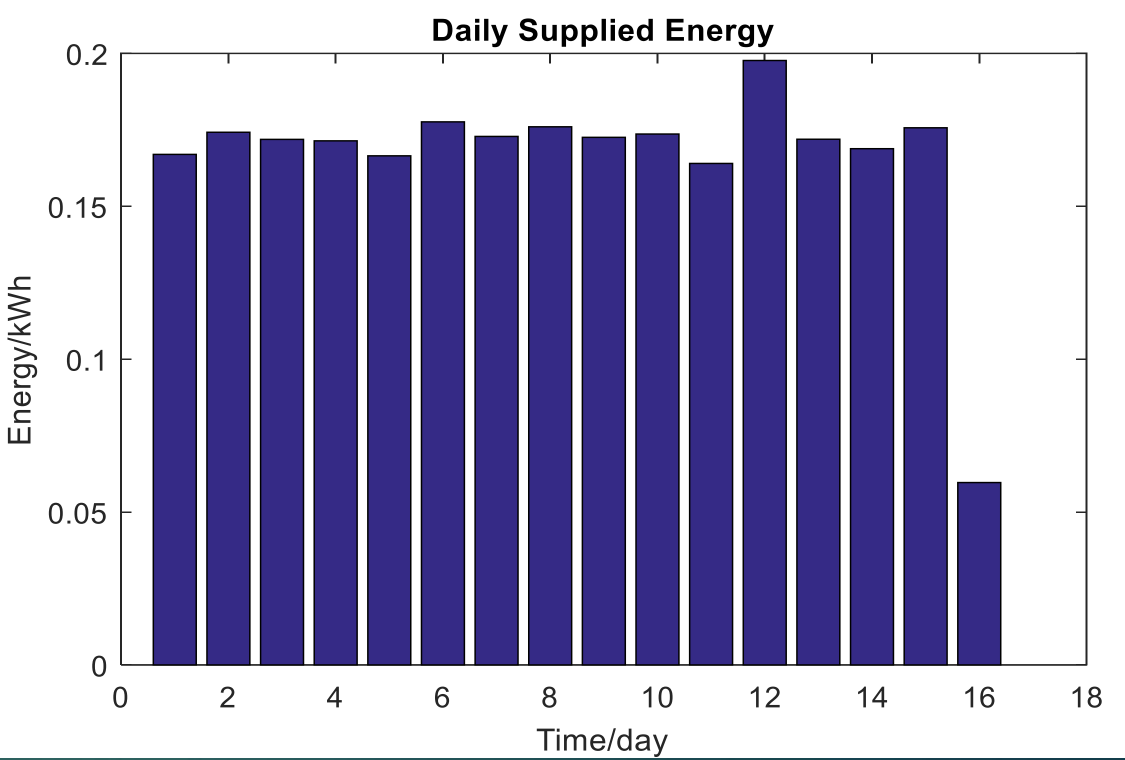
- Data Analysis



6. Data Logging and Visualization System

- Visualization of Data Analysis





8. Conclusion

- The designed hybrid power system achieves reliability, high renewable penetration and suitable payback time
- The designed dynamic model can realize stable operation under real-time conditions
- The DC voltage regulator can output stable DC voltage under extreme conditions
- The PID+R+CCF controller increases the waveform of the inverter
- The data logging system with synchronized radio communication can collect most recent sensor data and eliminate long cables between data loggers
- The python program on PC can achieve robust data transfer to thingspeak server

9. Future Work

- Design a solar-wind-diesel hybrid power system for the selected location
- Develop a time-delayed controller with parameters adjusted by fuzzy logic
- Develop a hardware for the voltage regulator&inverter system
- Include the function of data analysis in the python program
- Enable the Internet load control of the PV system

10. Publications

[1] Bojian Jiang, M. Tariq Iqbal, “Dynamic Modeling and Simulation of an Isolated Hybrid Power System in a Rural Area of China”, Journal of Solar Energy Volume 2018, doi: https://doi.org/10.1155/2018/5409069.

[2] Bojian Jiang, M. Tariq Iqbal, “The Dynamic Modeling and Simulation of Hybrid Power System for a Remote Location in China”, The 26th Annual Newfoundland Electrical and Computer Engineering Conference, 2017.

[3] Bojian Jiang, M. Tariq Iqbal, “Data Logging System and Data Visualization for an Isolated PV System”, to be submitted.

Thanks !