CATHODIC PROTECTION POWER SUPPLY IMPLEMENTATIONS USING SOLAR PHOTOVOLTAIC SYSTEM

By

SAYYID HAZIQ BIN HASSMORO

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)
MAY 2014

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan0

CERTIFICATION OF APPROVAL

CATHODIC PROTECTION POWER SUPPLY IMPLEMENTATIONS USING SOLAR PHOTOVOLTAIC SYSTEM

by

Sayyid Haziq Bin Hassmoro

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved by,

____

Supervisor AP. Dr. Zuhairi B. Hj. Baharudin
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

SAYYID HAZIQ BIN HASSMORO

ABSTRACT

Corrosion is a major problem for oil and gas operators as the cost consumed each year is fighting corrosion are staggeringly high. Along with the implementation of cost effective corrosion prevention methods, the race for reducing cost consumption still goes on. One of the common method used to prevent the corrosion is by implementing a cathodic protection system to control the environment of the protected object. It is controlled by an injected current which coming from a power supply. Common power supply is from transformer rectifier unit which get supply from Tenaga Nasional Berhad. An unexpected event such as lightning strike the power supply system may have chances to be interrupted. Interrupted by mean the earth leakage circuit breaker disconnect from the supply to the transformer rectifier unit. Once it being interrupted, the metal failed to be protected. Thus, corrosion can be occurred and lead to severe damage. The metal subjected to this project is the underground gas pipeline. This project propose a backup power supply by using solar photovoltaic (PV) system to have a continuous cathodic protection system.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express his utmost gratitude. The Almighty upon the completion of this Final Year Project. Without His love and mercy it is impossible to do anything related to this project.

A special thanks to respectable supervisor, Assoc. Prof. Dr. Zuhairi B. Hj. Baharudin for the opportunity given to the author to accomplish this project under his supervision. Attention, patience and knowledge shared by him had been really helpful in ensuring a steady progress of this project.

A very warm thanks goes to the Final Year Project Coordinator, Dr. Nasreen Bte. Badruddin for providing the author with all initial information required to begin the project.

The author would also like to express his gratitude towards the technicians in Electrical & Electronics Engineering department for assisting the author in using the required laboratory facilities.

Last but not least, deepest thanks to family and friends for their love and support to the author throughout this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

Photovoltaic (PV)

Transformer Rectifier Unit (TRU)

Impressed Current Cathodic Protection (ICCP)

Tenaga Nasional Berhad (TNB)

Cathodic Protection (CP)

Sacrificial Anode Cathodic Protection (SACP)

Fusion Bonded Epoxy (FBE)

Pulse Width Modulation (PWM)

Solar charger controller (SCC)

CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Problems of Corrosion

Corrosion affect in every each part of oil and gas field. From upstream (platform, pipeline, machine) to downstream. The corrosion contribute problems especially in the mechanical structure that may lead to serious problems. The depreciation of the strength also exponential through time. Its means that, the cost to prevent the corrosion will save a lot compare to the cost to fix the corrosion [1].

Due to low possibility to prevent corrosion, it has becoming more obvious that controlling corrosion rate may only be the most economical solution. Therefore, corrosion engineers are struggling in making the estimation the cost of their solutions of preventing corrosion in conjunction with estimating the useful life of the operating equipment in the production line.

1.1.2 Impacts of Corrosion

Mostly in oil and gas production industries, the impacts of corrosion are varies. Therefore, it often to affect more severe to environment and surrounding compare to metal loss in structure.

Table 1: Impacts of Corrosion

Impacts of Corrosion
1. Reduce the thickness of metal.
2. People injuries during structural failure.
3. Impurities inside pipeline during transportation.
4. Impurities affect the other major part in oil and gas.
5. Loss of technically significant surface properties.
6. Mechanical impairment.
7. Cost increase to recover from corrosion.

1.1.3 Corrosion Prevention Methods

Commonly, there are four steps to prevent corrosion from occur:

1. Adding an anode (the metal that being sacrifice) to the environments.
2. Adding a cathode (the place where metal is protected).
3. An electrical connection (rectifier) between the anode and cathode
4. A liquid medium, called the electrolyte, in contact with both the anode and cathode (to provide transportation medium) such as soil.

By retarding either the anodic or cathodic reaction, the rate of corrosion can be reduced. This can be achieved in several ways:

Table 2: Application of Corrosion Reduction

Concept	Main methods	Applications
Conditioning the metal	Coating the metal	Organic coating, metallic coating, inorganic coating
	Alloying the metal	Stainless steel
Conditioning the corrosive environment	Removal oxygen	Using strong reducing agents (i.e. sulphide)
	Corrosion inhibitors	Anodic inhibitors, cathodic inhibitors, adsorption type corrosion inhibitors, mixed inhibitors
Electrochemical control	Difference in metal potential	Cathodic protection, anodic protection

Of all the methods mentioned above, the project will be focused on electrochemical control which influence the difference in metal potential known as cathodic protection.

1.2 Problem Statement

The conventional method uses Transformer Rectifier Unit (TRU) to perform Impressed Current Cathodic Protection (ICCP). The TRU is bulky and requires large space. In addition, the TRU requires power supply from TNB which in large alternating current (AC) before convert it into low voltage. The problem arises when power supply from TNB has the chances to be interrupted due to lightning and etc. Other than that, the gap of power level between input and output at the TRU is large which is from 230 AC to 10 VDC. For industrial services, the power supply is expensive compared to domestic usage. Approach of using solar photovoltaic to reduce the monthly cost and maintenance cost. Therefore, this project is to propose a proper system of solar photovoltaic to supply power continuously for ICCP.

1.3 Objectives

1) To study the principles of impressed current cathodic protection in protecting underground carbon steel gas pipeline.
2) To investigate the application of solar photovoltaic in harvesting energy.
3) To propose a design of solar photovoltaic system for impressed current cathodic protection.

1.4 Scope of Study

The scope of work of this study includes the understanding the principle of cathodic protection for underground gas pipeline. The fundamental of CP is the most important for this project. In order to have a clear objective, impressed current cathodic protection is chosen to be the one focused in the CP system. It is because only impressed current technique uses conventional transformer rectifier unit as power supply for the CP system.

The conventional TRU also being included in the study due to its relativeness in providing power supply to replace it with solar photovoltaic. Therefore, the designing phase of the prototype related to solar photovoltaic is included.

For experimental purpose, the current and voltage from the output of the solar PV system will be monitored and recorded with Arduino. Current sensor and voltage divider are used to do the task.

CHAPTER 2: LITERATURE REVIEW

2.1 Cathodic Protection

One of the method that widely used to prevent corrosion in metal is Cathodic Protection (CP). CP is commonly applied in metal that is buried underground or in the sea such as oil and gas pipeline, submarines, underground tank, ship blade etc. Applying CP to the metal can increase the life span of the metal. CP can be divide into two (2) types. Firstly, Sacrificial Anode Cathodic Protection (SACP) and secondly Impressed Current Cathodic Protection (ICCP).

2.1.1 Sacrificial Anode Cathodic Protection (SACP)

For sacrificial anode, there will be no injected current as illustrated in figure 1, only the electrochemical reaction will provide the protection for the metal. It uses the natural potential difference that exists between the structure and second metal in the same environment to provide driving voltage [2].

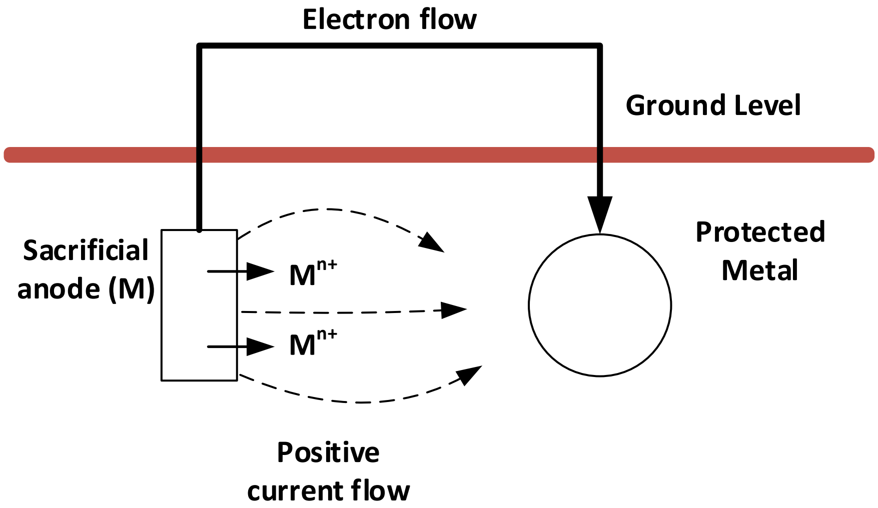


Figure 1: Schematic diagram of cathodic protection using sacrificial anode.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad (1)$$

$$O^{2} + 2H^{2}O + 4e^{-} \rightarrow 4OH^{-} \qquad (2)$$

From the chemical equation above, cathodic polarization decrease the speed of half-cell reaction (1) with an surplus of electrons, which decrease the speed of oxygen production and increase the OH^{-} production by reaction (2) [3].

2.1.2 *Impressed Current Cathodic Protection (ICCP)*

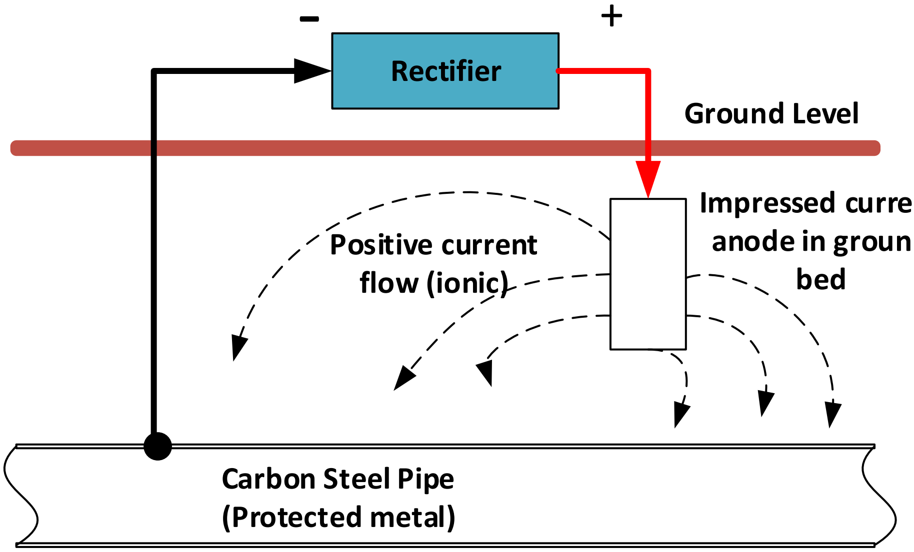


Figure 2: Schematic diagram of cathodic protection using impressed current technique.

Figure 2 depicts the use of rectifier or an external power supply to provide cathodic polarization of structure. The impressed current technique compromises of the rectifier, impressed current anode bed, aqueous solution environment and the metal to be protected.

Figure 2 also illustrates the movement of current from rectifier through anode bed to carbon steel pipe. From studies, the electrons move in the opposite direction to the movement of current. Thus, from the diagram, it shows that the rectifier injects the electron to the pipe specifically to the corroded surface of metal structures in order to accumulate the electrons to reduce the half-cell reaction and increases the rate of oxygen reduction [4]. Meanwhile, the anode bed (Magnesium or Zink) will decompose and become the sacrificial anode, where the corrosion normally occurs.

2.2 Transformer Rectifier Unit

Transformer rectifier unit consists of transformer and rectifier. The transformer used in the TRU is step down transformer which is used to reduce the alternating current voltage from the TNB supply. Then, the output from the transformer connects to the input of the rectifier. The rectifier function as a converter which convert alternating current to direct current. The impressed current technique requires direct current as power supply.

There are two types of transformer that are widely used in oil and gas industry depending on the location of the installation. For example offshore platforms, cast resin dry type transformers are preferred due to zero maintenance and small foot print. Meanwhile for onshore, oil type transformers as in figure 3 are used due to lower cost for installation and maintenance.

Figure 3: Oil type transformer for cathodic protection station.

Currently, the conventional transformer rectifier unit (TRU) utilise supply voltage of 230 VAC in a cathodic protection station as depict figure 4. Figure 4 shows the voltage level out from TRU is 10 VDC and to be injected to the pipe. This system depend on Tenaga Nasional Berhad (TNB) power supply which probably has the chance of tripping, thus the pipe would not be protected.

Figure 4: Transformer Rectifier Unit

The word corrosion is used to define the reaction of a material with its surroundings or electrolyte that produces measurable changes and can lead to impairment [1]. The material that interrelated to this project is from natural gas pipeline which is carbon steel. Meanwhile the surroundings is the soil due to the pipe is buried underground. Corrosion usually can occur in two condition. The first condition where corrosion happen in the same metal with different environment. Secondly, the corrosion occurs in different metal but with the same environment. In every corrosion processes, the speed of the anodic reaction must equal the speed of the cathodic one [5, 6].

Rectifier unit supplies current for ICCP [1, 7]. From figure 2, the rectifier unit provides direct current voltage to the anode bed. The current flows through the anode bed and jump to the pipe. Throughout this method, corrosion can be minimized to nearly zero through cathodic protection and well-maintenances system provide protection periodically [3, 8]. Over protection to the underground pipeline may lead to coating defect.

Coating is primary form of corrosion prevention followed by other prevention system [9]. The purpose of a barrier coating is to insulate the anode and cathode of the corrosion cell from the environment [2]. For example, three (3) layer fusion bonded epoxy (FBE) that is used for natural gas pipeline. In genuineness, there is no perfect design that can prevent corrosion in total. The coating also provided with a coating defect that as big as pin hole which provide a complete circuit for cathodic protection system.

2.2 Solar Photovoltaic

The term photovoltaic is derived from the Greek work “photo” which means light and “volta” named for Alexander Volta, who did some of early work in electrical development [10]. From the two nouns it combined and form photovoltaic.

Harvesting sunlight into electricity is one of the renewable source that can be collected using solar photovoltaic system. The electricity generated usually being stored in battery or used directly. It also can be used to support the grid depending on its rating. Solar PV can be one of the reliable and green source of electricity that have many application worldwide [11].

In solar PV system, contain four types of major components depend on criteria of the design itself. A simple solar PV system includes solar panel, charger controller, battery and converter or inverter. In this proposed system, the solar panel will collect the sun radiation and convert into electricity as the output. Then, the charger controller will control the input to the battery to prevent overcharging and several protection. Thus, it protects the battery from damage and increases the lifespan of the battery itself. The battery is the place where the electrical energy stored in order to provide current supply to the metal employed as the cathode [12]. Last but not least, the inverter either to change direct current into alternating current or vice versa and the converter that can be used to change the level of voltage or current depending on the application for the system [13].

The most commercial solar cells nowadays are silicon-based structures [10]. The photovoltaic (PV) power technology uses semiconductor cells (wafers), generally several square centimeters in size. From the solid-state physics point of view, the cell is basically a large area p-n diode with the junction positioned close to the top surface. The cell converts the sunlight into direct current electricity. Numerous cells are assembled in a module to generate required power.

The photovoltaic cell, then, converts light directly into electricity. The process produce electricity without producing carbon dioxide [14].The physics of the PV cell is very similar to the classical p-n junction diode is shown in figure 4.

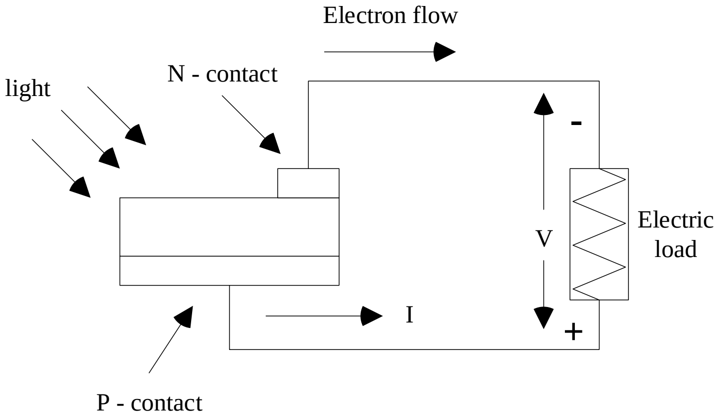


Figure 5: Physics of Solar Photovoltaic System

After the junction absorbed the solar light, the absorbed photons energy drained to the electron system of the material, produce charge carries that parted at the junction. The charge carriers may be electron-ion pairs in a liquid electrolyte or electron-hole pairs in a solid semiconducting material. The presence of charge carriers in the junction produce a potential sloop. It accelerated through an electric field and circulate as current. Thorough formula of power is equal to current measured squared multiply by the resistance of the external circuit. The remaining power will dissipates as heats.

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart

The project starts with gathering information through journals and research paper. The information then analyze critically to gain the core idea of the project based on the title proposed. From the title proposed, the problem statement is projected to lead the objectives. The case studies are constructed after stated the objectives. The literature reviews are focused on cathodic protection.

The project main activities are basically divided into two sessions. One is the activities that are conducted to calculate transformer rectifier unit power requirement for cathodic protection unit and the other activities are conducted to design solar PV system to accommodate the power requirement from transformer rectifier unit.

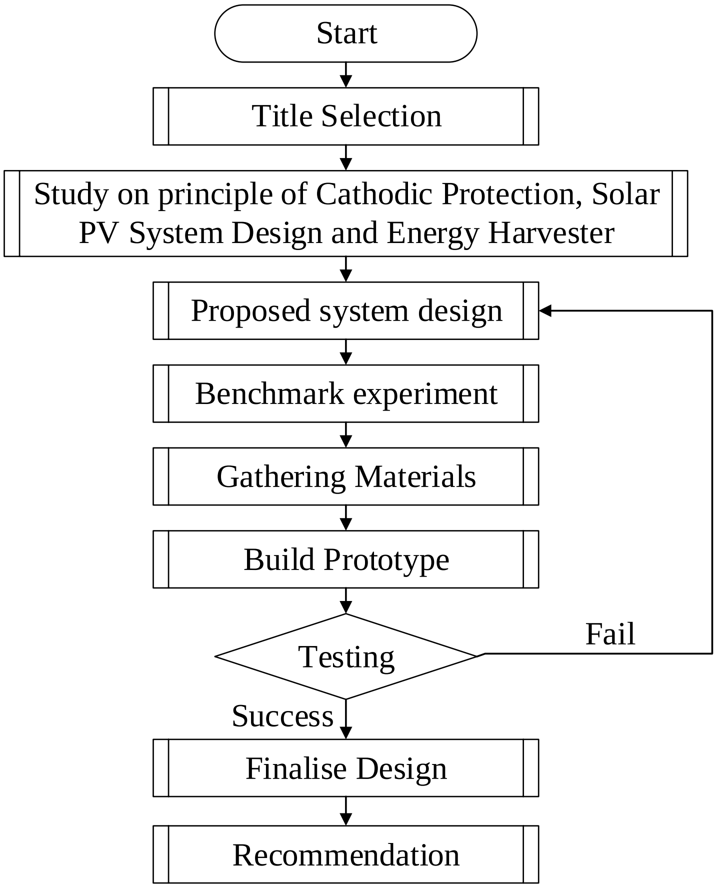


Figure 6: Final Year Project Flowchart

3.2 Activities Description

To elaborate more on the previous section, the system design basically involve four phases (not in actual sequence):

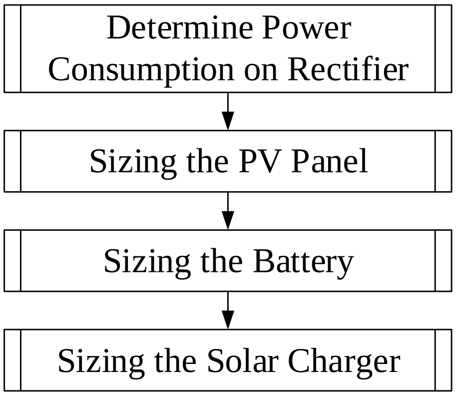


Figure 7: Four Phase of Designing Solar Photovoltaic System

3.2.1 Solar Photovoltaic System Design

The solar PV system for the prototype consist of solar photovoltaic, charger controller, battery and converter as depicted in figure 8. The solar PV module collects the solar radiation to be converted into electricity. The charger controller controls the charging with pulse width modulation switching to increase the charging battery efficiency and long lasting. The battery is where the electron stored and discharge to load. The converter controls the level of output voltage from the battery.

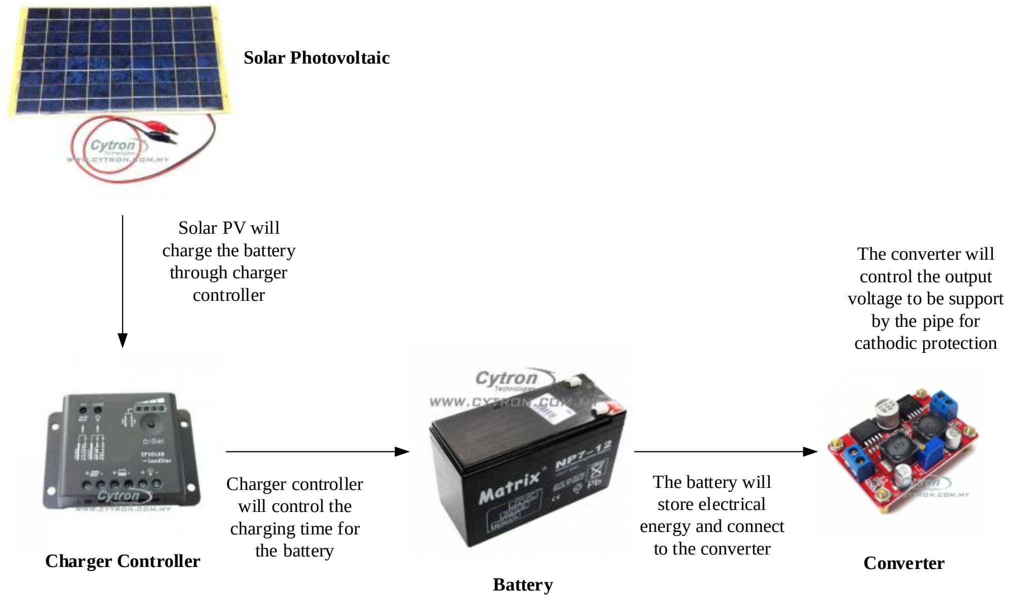


Figure 8: Material Selection with Relation between Components

Power Consumption

From the TRU at CP station, the rectifier requires to supply 10V and 2.5A for 2 hours per day (maximum response time). The power consumption from the rectifier calculated as below.

$$10V \times 2.5A \times \frac{2h}{day} = 50Wh/day$$

Total PV panel energy needed is the energy required per day multiply with added energy lost in system.

$$\frac{50Wh}{day} \times 1.3 = 65Wh/day$$

Size of PV Panel

The solar PV panel used is polycrystalline type to save the area of space required. For the size of PV panel, the total Watt-peak (Wp) calculated from PV panel capacity needed divide with panel generation factor in Malaysia which is 3.4.

$$\frac{65Wh/day}{3.4} = 19.11Wp$$

Number of PV panels needed calculated as below. The 10Wp is from the datasheet of solar panel.

$$\frac{19.11Wp}{10Wp} = 1.911 \approx 2$$

The number of PV panels needed are 2 modules.

Battery Sizing

Total uses energy for the system calculated as below.

$$25W \times 2hours = 50Wh$$

Nominal battery voltage = 12 V

Nominal Ampere-hours battery = 7.2Ah

Days of autonomy = 1 days

Battery capacity calculated as below.

$$50Wh \times \frac{1}{0.85 \times 0.6 \times 12} = 8.17Ah$$

Total Ampere-hours required = 8.17 Ah

Number of battery required as below.

$$\frac{8.17Ah/day}{7.2Ah\ /\ day\ unit} = 1.1347\ unit$$

Total number of battery required is 2 units.

LS0512 Solar Charger Controller Selection

Solar charger controller (SCC) selected for this project is LandStar series solar charger controller that adopts the most advanced digital technique and operates fully automatically. It use Pulse Width Modulation (PWM) technique to charge the battery to increase the lifetime of battery and improve the solar system performance. The switching part is taken by electronic switch; MOSFET. It adopt temperature compensation, correct the charging and discharging parameters automatically. Included with electronic protection such as overcharging or discharging, overload, reverse polarity and even short circuit.

The SCC rating is 60 Watt. By default, it can support up to 6 units of 10 Watt solar PV panel. The number of battery that can be installed is unlimited but will increase the time take for the battery to fully charge.

3.2.2 Prototype Casing Design

The casing for the prototype is designed by using AutoCad software. It designed to be compact and portable as it will be installed together with TRU in CP station. The material used for the casing is acrylic, which easy to cut and fabricate. The figure 9 below portrays the second version of the prototype casing. The first version of design is much more bulky compared to second version.

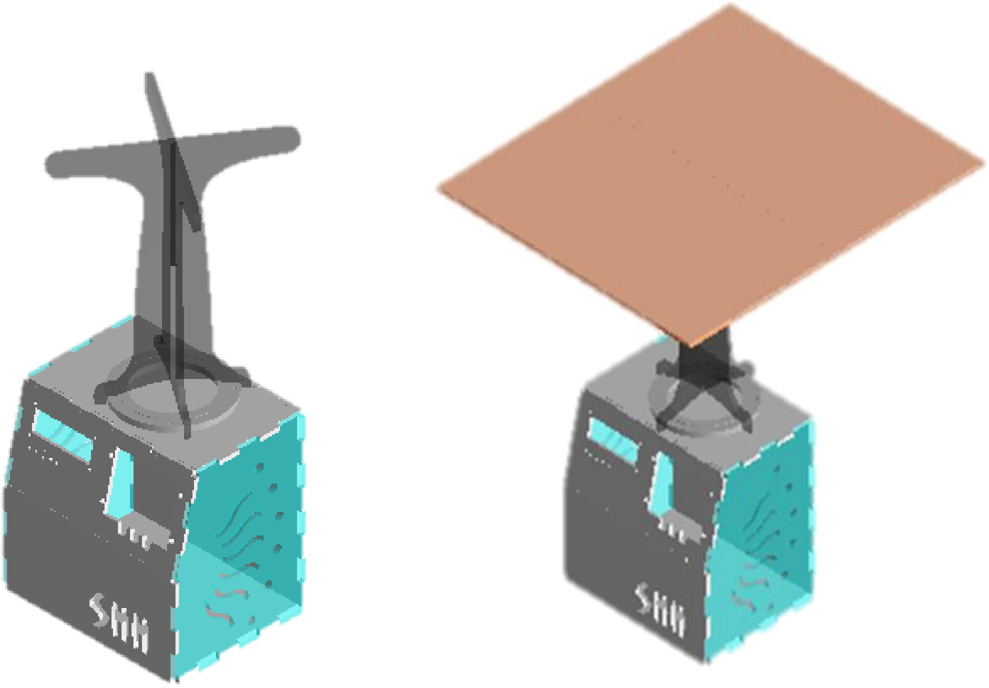
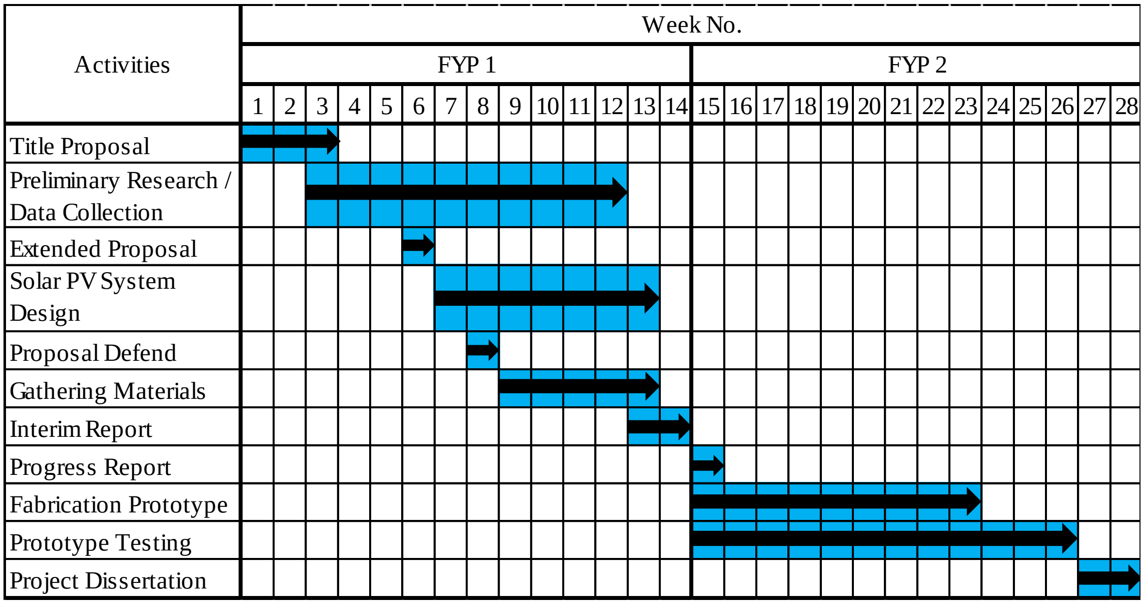


Figure 9: The Casing of Prototype

3.3 Project Gantt chart

The Gantt chart for Final Year Project I and Final Year Project II are shown below.

Table 3: Gantt chart for Final Year Project I and Final Year Project II



Activities	Week No.																											
	FYP 1														FYP 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Title Proposal	■	■	■																									
Preliminary Research / Data Collection			■	■	■	■	■	■	■	■	■	■																
Extended Proposal						■																						
Solar PV System Design							■	■	■	■	■	■	■															
Proposal Defend								■																				
Gathering Materials									■	■	■	■	■															
Interim Report													■	■														
Progress Report															■													
Fabrication Prototype															■	■	■	■	■	■	■	■	■					
Prototype Testing															■	■	■	■	■	■	■	■	■	■	■	■		
Project Dissertation																											■	■

The Gantt chart is divided into FYP I and FYP II. In FYP I, the schedule is majorly on study, research and documentation for cathodic protection and solar PV design. The project is focused in designing power supply for TRU by using solar. The designing part require basic calculation to calculate total number of solar PV module required and total number of battery required. This project systematically follows the schedule in order to meet the expectation of the results. Meanwhile in FYP II, the schedule is critically on prototyping completion and testing. The prototype is designed and fabricated before being tested. The testing conducted to measure and record the current and voltage of the battery across the time.

3.4 Project Key Milestone

Towards the project research, key milestone being set up to accomplish the desired design. The key milestones are as follow:

Table 4: Key Milestones for Final Year Project

Activities	Week No.																											
	FYP 1														FYP 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Completetion of the Title Proposal by FYP Committee			◆																									
Completion of the Preliminary Research and Data Collection												◆																
Completion of Solar PV System Design													◆															
Completion of Interim Report Documentation														◆														
Completion of Fabrication Prototype																							◆					
Completion of Prototype Testing																										◆		
Completion of Project Dissertation																												◆

The milestones for FYP I is achieved perfectly according to the time frame planned. In FYP II has three milestones which are completion of fabrication prototype, completion of prototype testing and completion of project dissertation. The progress report is completed in week 8. The prototype is tested together with completion of fabrication. The project dissertation is on schedule for completion.

CHAPTER 4: RESULTS AND DISCUSSION

In order to prepare a stable system before being implemented, few parameters need to be analyzed such as time taken for battery to reach fully charge, the lowest voltage before the charger controller trigger to recharge. These two parameters are crucial in term of readiness to be operate at interrupted time.

From the figure 10, the voltmeter and ammeter are connected to monitor the parameters through time. The objective of recording the current and voltage is to study the fluctuating of the current and voltage which affected by solar radiation. Arduino is used together with current sensor to collect the value for the parameter.

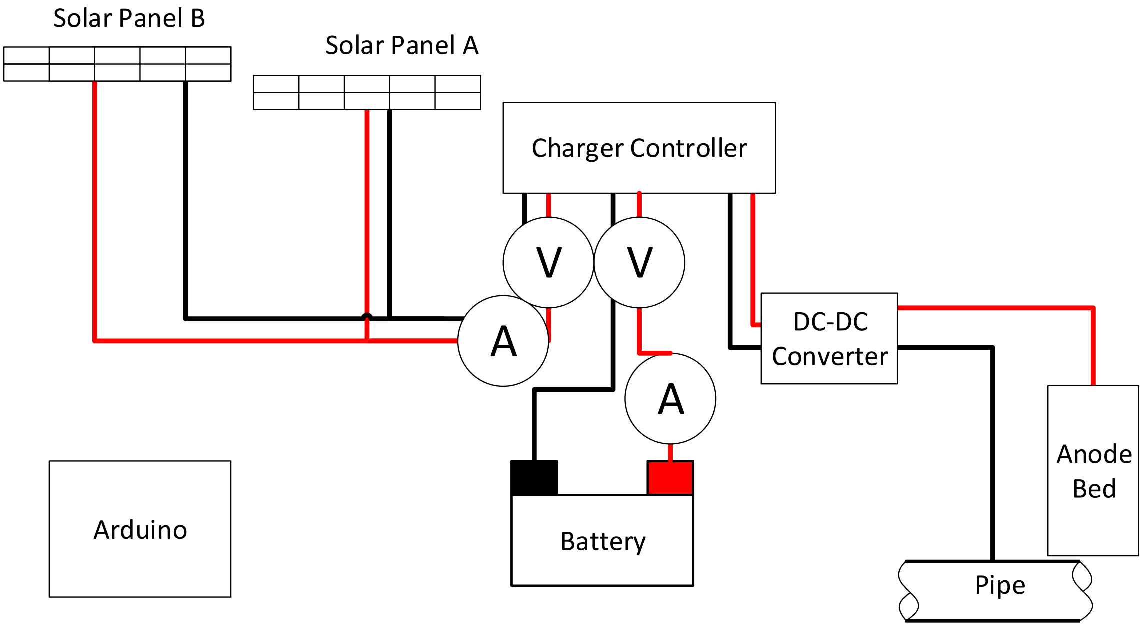


Figure 10: Voltmeter and Ammeter Position for Data Measurement

Figure 11: Testing Conducted under Direct Sunlight

Table 5 depicts the voltage of battery that is not connected to charger controller, battery that is connected to charger controller and solar PV that is connected in parallel. The current flows measured shows from the SCC to battery, from solar PV A to SCC and from solar PV B to SCC.

Table 5: Parameters Recorded for Voltage and Current of the Solar PV System

Time	Battery			Solar PV			Time	Battery			Solar PV		
	Voltage (V)	Current (A)	Open Circuit Voltage (V)	Voltage (V)	Current (A)	Open Circuit Voltage (V)		Voltage (V)	Current (A)	Open Circuit Voltage (V)	Voltage (V)	Current (A)	Open Circuit Voltage (V)
2:37	12.934	0.35	12.617	13.029	0.35	20.271	3:32	13.444	0.56		13.551	0.56	
2:40	12.797	0.12		12.863	0.12		3:35	13.36	0.45		13.446	0.45	
2:45	12.791	0.09		12.851	0.1		3:37	13.417	0.5		13.513	0.5	
2:48	13.081	0.47		13.207	0.47		3:40	13.058	0.008		13.112	0.009	
2:50	13.172	0.46		13.256	0.46		3:42	13.476	0.55		13.557	0.56	
2:52	13.161	0.44		13.27	0.44		3:44	13.478	0.56		13.58	0.56	
2:53	13.129	0.33		13.169	0.33		3:46	13.113	0.09		13.143	0.1	
2:56	12.781	0.23		13.084	0.23		3:49	13.337	0.4		13.38	0.4	
2:58	12.949	0.13		13.011	0.14		3:50	13.388	0.45		13.494	0.45	
3:00	13.131	0.33		13.194	0.33		3:52	13.372	0.42		13.456	0.42	
3:02	13.296	0.52		13.381	0.53		3:54	13.033	0.06		13.088	0.07	
3:03	13.431	0.66		13.491	0.65		3:57	12.984	0.03		13.091	0.05	
3:05	13.332	0.55		13.507	0.55		3:59	13.049	0.07		13.078	0.08	
3:07	13.1	0.23		13.167	0.24		4:01	13.374	0.43		13.476	0.44	
3:10	13.144	0.24		13.288	0.25		4:03	13.425	0.47		13.525	0.47	
3:11	13.315	0.63		13.475	0.63		4:05	13.473	0.45		13.662	0.45	
3:13	13.373	0.65		13.497	0.65		4:07	13.462	0.47		13.533	0.47	
3:14	13.503	0.69		13.615	0.69		4:09	13.455	0.42		13.942	0.42	
3:17	13.206	0.33		13.293	0.33		4:10	13.395	0.45		13.539	0.46	
3:18	13.349	0.55		13.449	0.55		4:11	13.411	0.4		13.501	0.41	
3:21	13.28	0.43		13.363	0.44		4:13	13.242	0.23		13.319	0.24	
3:22	13.376	0.5		13.472	0.5		4:15	13.338	0.35		13.426	0.36	
3:24	13.39	0.49		13.487	0.5		4:17	13.42	0.4		13.512	0.4	
3:26	13.393	0.53		13.516	0.53		4:19	13.334	0.31		13.42	0.32	
3:28	13.416	0.56		13.556	0.56		4:21	13.288	0.26		13.351	0.27	
3:30	13.449	0.56		13.546	0.56		4:23	13.266	0.25	12.999	13.343	0.26	

The data recorded in table 5 for every set of period from 2:37PM until 4:25PM shows the instantaneous voltage and current for battery and solar PV. The voltage recorded for battery (not connected) initially at 12.617V and finished at 12.999V. The battery need to be measured in open circuit condition before and after the charging in order to isolate the battery from the SCC circuit. Other than that, the SCC is using PWM switching to charge the battery, once the battery is disconnected from the SCC and connected back, the PWM switching will automatically restart its period from smaller to bigger step size. Thus, it will affect the time take for the battery to fully charge.

For the voltage of parallel solar PV, the initial value is 19.804V which is not connected to SCC and after connected to SCC the voltage drop to maximum of 13.942V. This is due to power consume in the SCC circuit. The current recorded over the period for the battery started at 0.35A and finished at 0.25A. For the solar PV, the current started at 0.350A and 0.26A. From the data, it shows that approximately input current equal to output current. The input current is the current from the solar PV and the output current is charging current.

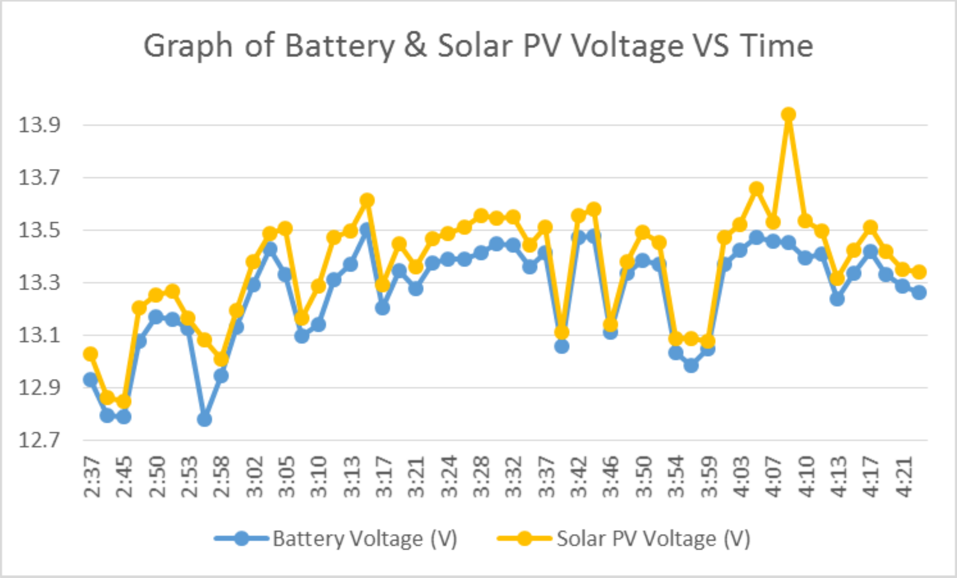


Figure 12: Graph of Voltage versus Time

From figure 12, the battery voltage is lower than solar PV voltage. This is due to input voltage which is from the solar PV will always higher than the output which is the charging voltage. When it is connected to the SCC, the voltage will drop due to power consumption from the SCC circuit.

From the voltage of solar PV, the slope is changing rapidly. This is due to climate change such as the weather become cloudy and back to normal at sudden. This situation is unpredictable and not under human control. The rapid changes also from the SCC itself which has different type of mode for charging to prevent overheating and excessive battery gassing. The variety of mode is for long lasting of battery usage. When the battery is fully charge at 14V, the PWM will go to float charge mode which will reduce the voltage for charging the battery. At this stage, loads draw power directly from the battery.

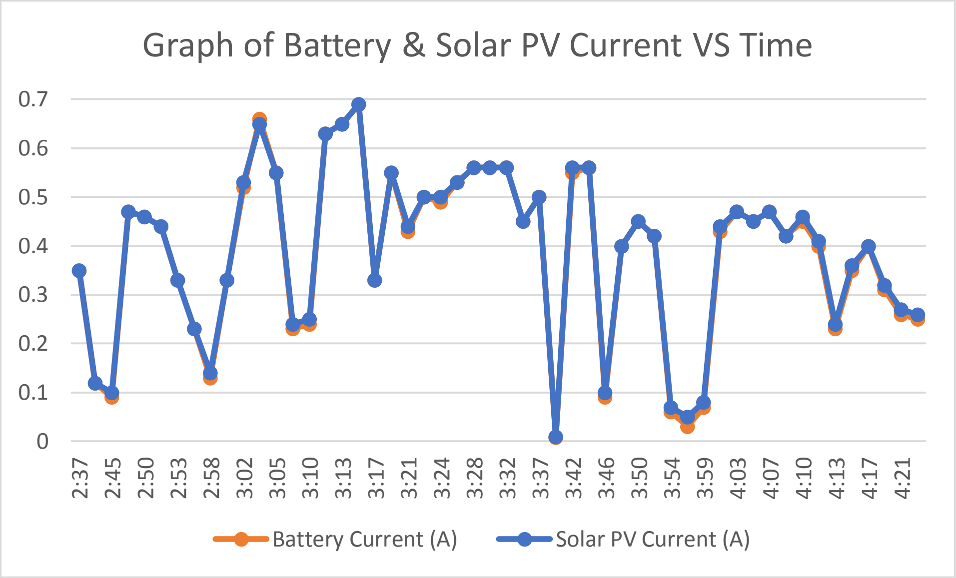


Figure 13: Graph of Current versus Time

From figure 13 above, it plots the value for current across the time from 2.37PM to 4.25PM. The current from the solar PV approximately equal to the current injected to the battery. This is due to solar PV supplied current affected from the solar radiation. When the solar radiation is not sufficient for the solar PV, low power will be supplied to the battery.

CHAPTER 5: CONCLUSION

The objectives for this project are achieved. The principles of impressed current cathodic protection in protecting underground carbon steel gas pipeline is studied with guided from the references. The investigation of solar photovoltaic in harvesting energy has been done in order to design the solar PV system for impressed current cathodic protection. The prototype of solar PV system for impressed current cathodic protection has been completed. The data collected contain high efficiency of 99.2% based on input and output of the system.

The solar PV system have a lot of potential to be coupled together with the TRU for cathodic protection system. Besides giving continuous supply during interrupted supply, solar PV reduces the cost of commissioning and maintenance. Thus, the underground carbon steel underground gas pipeline is continuously protected.

CHAPTER 6: RECOMMENDATION

The system is designed to become the backup supply after the primary supply having a failure, to become fully green system, it is recommended to become the primary supply for the CP system.

Other than that, the system load is not always fixed at a value due to soil resistivity and environment. Therefore, load monitoring is recommended. It will give analog input that can be analysed and programme using Arduino. Thus, to have a monitoring voltage using Arduino and pulse width modulation (PWM) that can adapt the voltage to be in the range of voltage where the pipe is protected is one of the recommendation that can be included.

In order to receive optimum solar radiation, the solar panel need to always facing the sun. Due to that, the system can be improved by a controlling device to control the angle of the solar panel to always facing the sun.

From the result and discussion, it is important to have consistency in data sampling. In order to have the consistency the data sampling need to be increased into 30 days in order to improve the analysis on charging of the battery.

REFERENCES

[1] W. S. W. Von Baeckmann, and W. Printz, Editors, *Handbook of Cathodic Corrosion Protection - Theory and Practice of Electrochemical Protection Processes*, 3rd ed. Houston, TX: Gulf Professional Publishing Company, 1997.

[2] S. M. Bashi, N. F. Mailah, and M. A. Radzi, "Cathodic protection system," in *Power Engineering Conference, 2003. PECon 2003. Proceedings. National*, 2003, pp. 366-370.

[3] K. In-Dong and N. Eui-Cheol, "Module-type switching rectifier for cathodic protection of underground and maritime metallic structures," *Industrial Electronics, IEEE Transactions on,* vol. 52, pp. 181-189, 2005.

[4] W. Xiaohua, H. Meijiao, H. Yao, G. Jun, G. Shouwei, and M. Zhonghua, "Design and implementation of the remote control of ICCP systems," in *Control and Decision Conference (2014 CCDC), The 26th Chinese*, 2014, pp. 3543-3546.

[5] F. Ferraris, M. Parvis, E. Angelini, and S. Grassini, "Measuring system for enhanced cathodic corrosion protection," in *Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International*, 2012, pp. 1583-1587.

[6] S. A. Bradford, *Corrosion Control*. New York: Van Nostrand Reinhold, 1993.

[7] V. A. a. C. J. L. Booker, *Cathodic Protection - Theory and Practice*. Chichester, U.K., 1986.

[8] P. Pedeferri, "Cathodic Protection and Cathodic prevention conservation and building materials," vol. 10, ed, 1996, pp. 391-402.

[9] P. R. Roberge, *Handbook of Corrosion Engineering*. Hightstown, N.J.: The McGraw-Hill Companies, Inc, 2000.

[10] M. O. Durham, "Solar Powered Cathodic Protection Using Residual Potential," *Industry Applications, IEEE Transactions on,* vol. IA-23, pp. 433-439, 1987.

[11] K. M. Trautz, P. P. Jenkins, R. J. Walters, D. Scheiman, R. Hoheisel, R. Tatavarti, *et al.*, "Mobile Solar Power," *Photovoltaics, IEEE Journal of,* vol. 3, pp. 535-541, 2013.

[12] S. S. B, K. P. Pranav, and K. Raj R, "Solar powered corrosion prevention in iron pipelines using Impressed Current Cathodic Protection," in *Environment and*

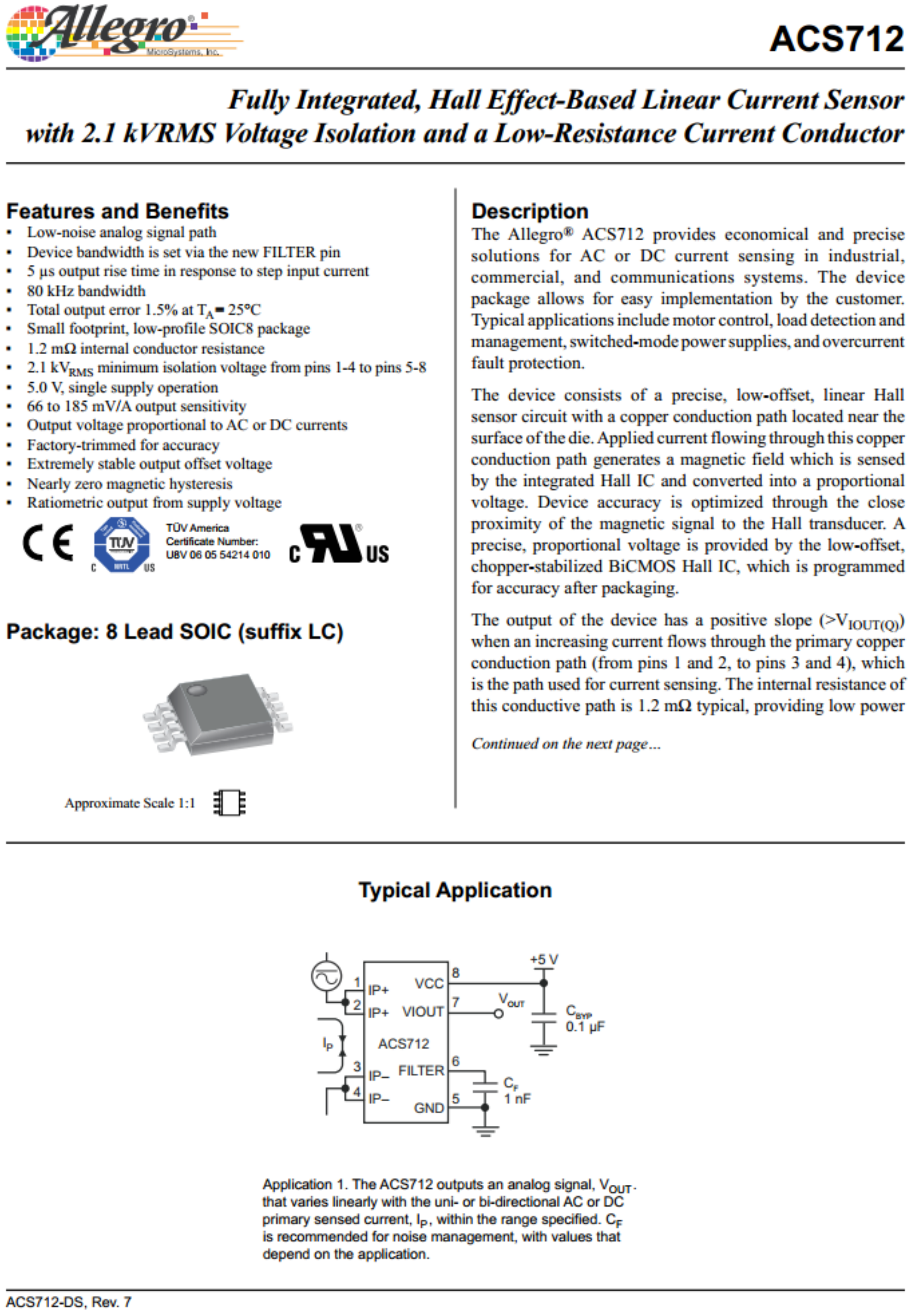
Electrical Engineering (EEEIC), 2014 14th International Conference on, 2014, pp. 372-377.

[13] P. R. Mishra, J. C. Joshi, and B. Roy, "Design of a solar photovoltaic-powered mini cathodic protection system," *Solar Energy Materials and Solar Cells,* vol. 61, pp. 383-391, 4/1/ 2000.

[14] H. N. Afrouzi, S. V. Mashak, A. M. Dastgheib, and J. Tavalaei, "Economic Sizing of Solar Array for a Photovoltaic Building in Malaysia with Matlab," in *Informatics and Computational Intelligence (ICI), 2011 First International Conference on*, 2011, pp. 306-311.

APPENDICES

Appendix A – ACS712 Hall Effect Current Sensor Datasheet



ACS712

Fully Integrated, Hall Effect-Based Linear Current Sensor with 2.1 kVRMS Voltage Isolation and a Low-Resistance Current Conductor

Features and Benefits

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 μs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at $T_A = 25°C$
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kV_{RMS} minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage

TÜV America
Certificate Number:
U8V 06 05 54214 010

Package: 8 Lead SOIC (suffix LC)

Approximate Scale 1:1

Description

The Allegro® ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, switched-mode power supplies, and overcurrent fault protection.

The device consists of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging.

The output of the device has a positive slope ($>V_{IOUT(Q)}$) when an increasing current flows through the primary copper conduction path (from pins 1 and 2, to pins 3 and 4), which is the path used for current sensing. The internal resistance of this conductive path is 1.2 mΩ typical, providing low power

Continued on the next page…

Typical Application

Application 1. The ACS712 outputs an analog signal, V_{OUT}. that varies linearly with the uni- or bi-directional AC or DC primary sensed current, I_P, within the range specified. C_F is recommended for noise management, with values that depend on the application.

ACS712-DS, Rev. 7

Description (continued)

loss. The thickness of the copper conductor allows survival of the device at up to 5× overcurrent conditions. The terminals of the conductive path are electrically isolated from the sensor leads (pins 5 through 8). This allows the ACS712 current sensor to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques.

The ACS712 is provided in a small, surface mount SOIC8 package. The leadframe is plated with 100% matte tin, which is compatible with standard lead (Pb) free printed circuit board assembly processes. Internally, the device is Pb-free, except for flip-chip high-temperature Pb-based solder balls, currently exempt from RoHS. The device is fully calibrated prior to shipment from the factory.

Selection Guide

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
ACS712ELCTR-05B-T	Tape and reel, 3000 pieces/reel	–40 to 85	±5	185
ACS712ELCTR-20A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±20	100
ACS712ELCTR-30A-T	Tape and reel, 3000 pieces/reel	–40 to 85	±30	66

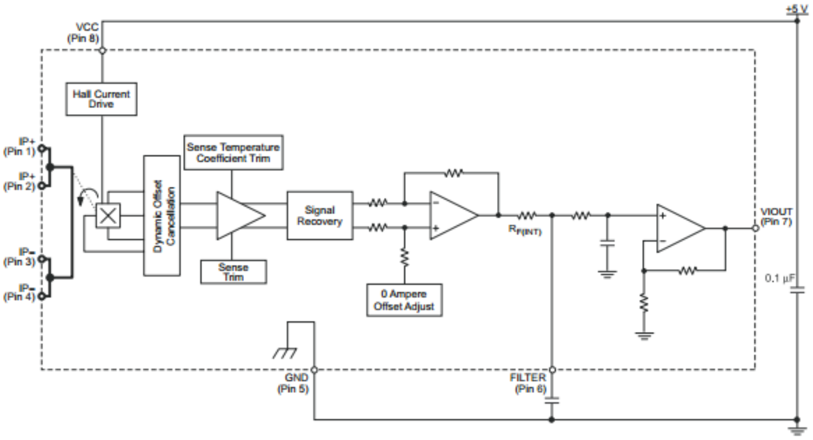
*Contact Allegro for additional packing options.

Absolute Maximum Ratings

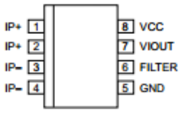
Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		–0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		–0.1	V
Reinforced Isolation Voltage	V_{ISO}	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	2100	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	184	V_{peak}
Basic Isolation Voltage	$V_{ISO(bsc)}$	Pins 1-4 and 5-8; 60 Hz, 1 minute, T_A=25°C	1500	V
		Voltage applied to leadframe (Ip+ pins), based on IEC 60950	354	V_{peak}
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	–40 to 85	°C
Maximum Junction Temperature	T_J(max)		165	°C
Storage Temperature	T_{stg}		–65 to 170	°C

Parameter	Specification
Fire and Electric Shock	CAN/CSA-C22.2 No. 60950-1-03 UL 60950-1:2003 EN 60950-1:2001

Functional Block Diagram

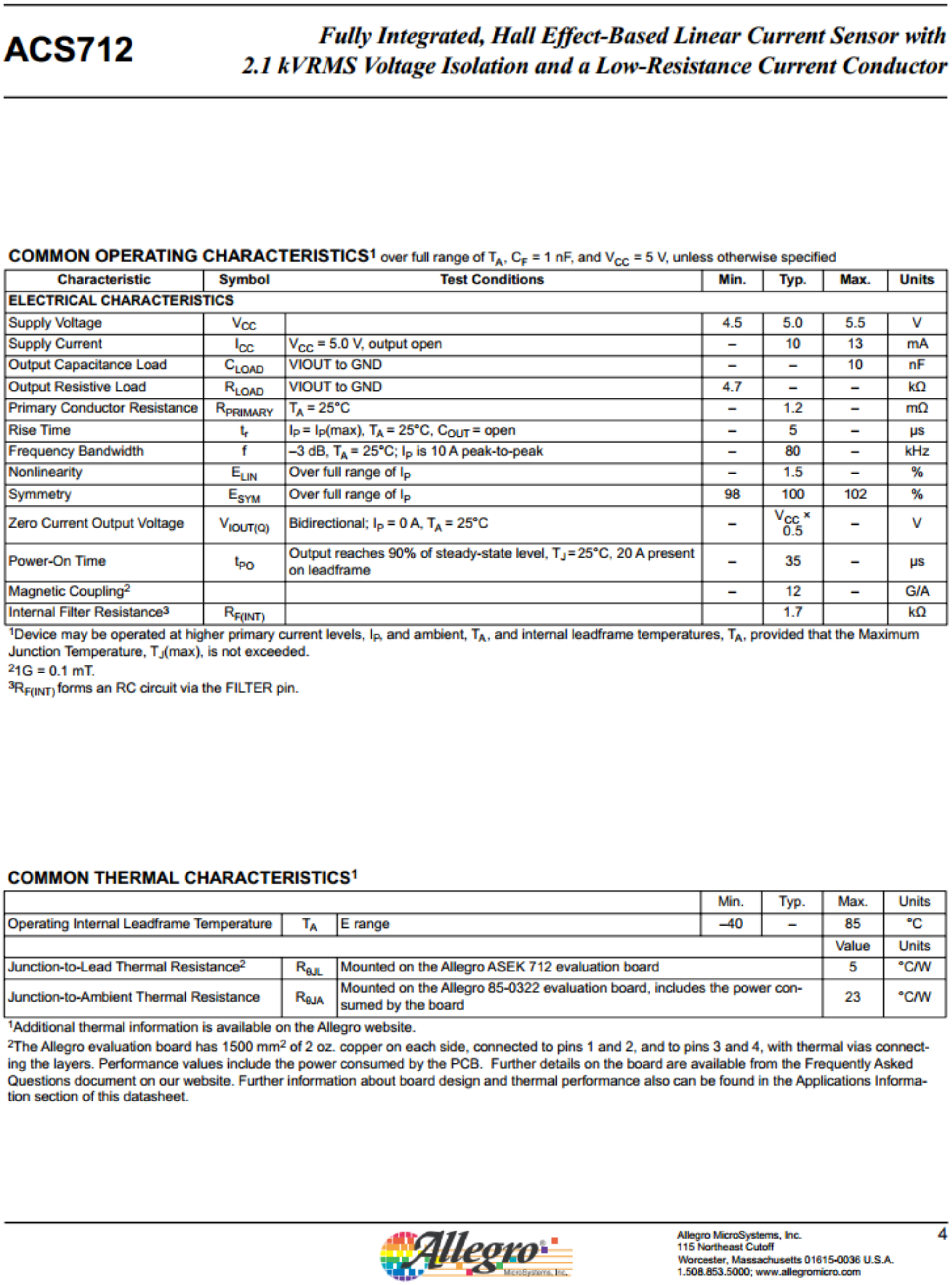


Pin-out Diagram



Terminal List Table

Number	Name	Description
1 and 2	IP+	Terminals for current being sensed; fused internally
3 and 4	IP–	Terminals for current being sensed; fused internally
5	GND	Signal ground terminal
6	FILTER	Terminal for external capacitor that sets bandwidth
7	VIOUT	Analog output signal
8	VCC	Device power supply terminal



COMMON OPERATING CHARACTERISTICS[1] over full range of T_A, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
ELECTRICAL CHARACTERISTICS						
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	–	10	13	mA
Output Capacitance Load	C_{LOAD}	VIOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VIOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	T_A = 25°C	–	1.2	–	mΩ
Rise Time	t_r	$I_P = I_P(max)$, T_A = 25°C, C_{OUT} = open	–	5	–	μs
Frequency Bandwidth	f	–3 dB, T_A = 25°C; I_P is 10 A peak-to-peak	–	80	–	kHz
Nonlinearity	E_{LIN}	Over full range of I_P	–	1.5	–	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{IOUT(Q)}$	Bidirectional; I_P = 0 A, T_A = 25°C	–	V_{CC} × 0.5	–	V
Power-On Time	t_{PO}	Output reaches 90% of steady-state level, T_J = 25°C, 20 A present on leadframe	–	35	–	μs
Magnetic Coupling[2]			–	12	–	G/A
Internal Filter Resistance[3]	$R_{F(INT)}$			1.7		kΩ

[1] Device may be operated at higher primary current levels, I_P, and ambient, T_A, and internal leadframe temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.

[2] 1G = 0.1 mT.

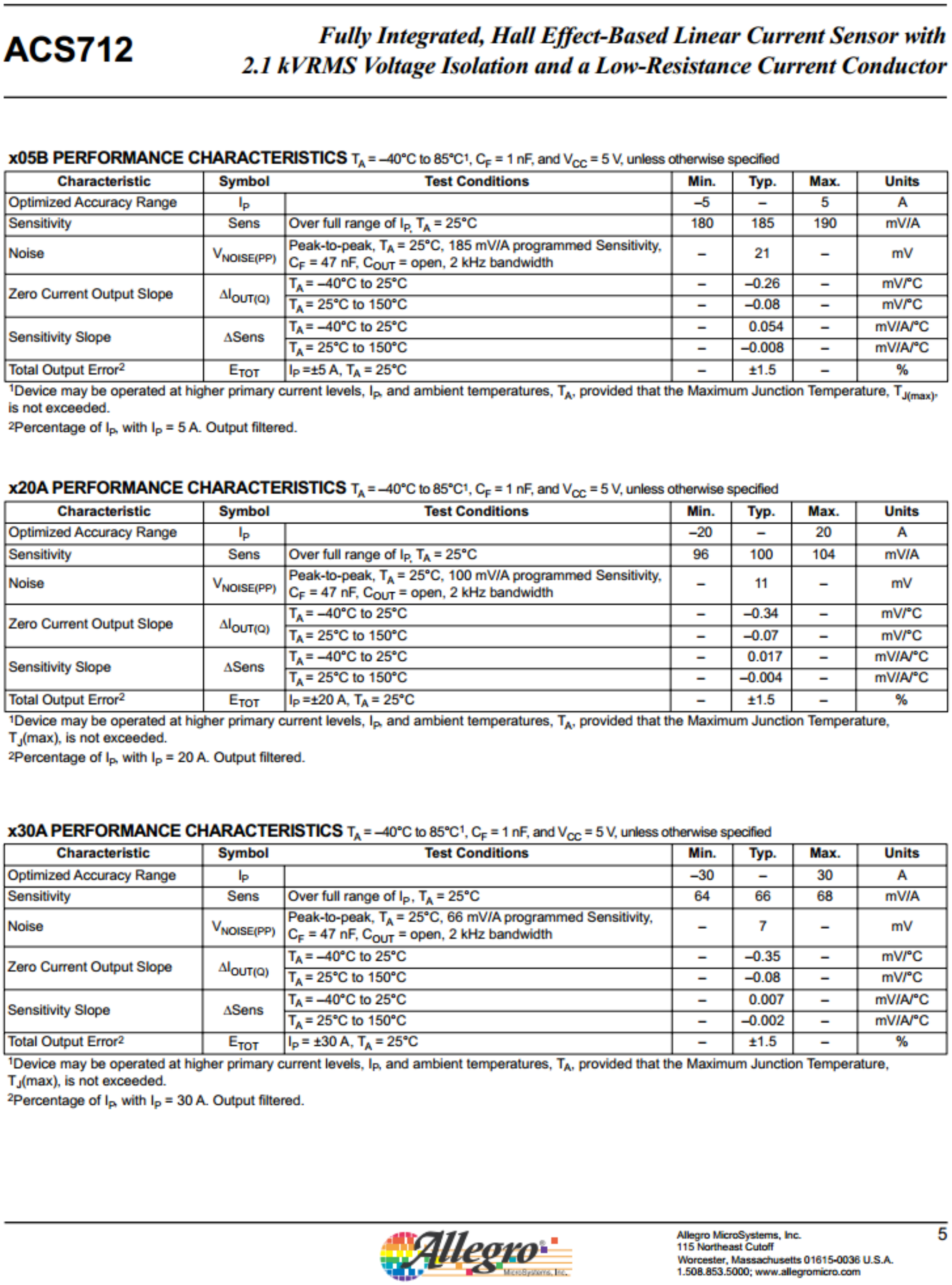
[3] $R_{F(INT)}$ forms an RC circuit via the FILTER pin.

COMMON THERMAL CHARACTERISTICS[1]

			Min.	Typ.	Max.	Units
Operating Internal Leadframe Temperature	T_A	E range	–40	–	85	°C
					Value	Units
Junction-to-Lead Thermal Resistance[2]	$R_{\theta JL}$	Mounted on the Allegro ASEK 712 evaluation board			5	°C/W
Junction-to-Ambient Thermal Resistance	$R_{\theta JA}$	Mounted on the Allegro 85-0322 evaluation board, includes the power consumed by the board			23	°C/W

[1] Additional thermal information is available on the Allegro website.

[2] The Allegro evaluation board has 1500 mm² of 2 oz. copper on each side, connected to pins 1 and 2, and to pins 3 and 4, with thermal vias connecting the layers. Performance values include the power consumed by the PCB. Further details on the board are available from the Frequently Asked Questions document on our website. Further information about board design and thermal performance also can be found in the Applications Information section of this datasheet.



ACS712 *Fully Integrated, Hall Effect-Based Linear Current Sensor with 2.1 kVRMS Voltage Isolation and a Low-Resistance Current Conductor*

x05B PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–5	–	5	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	180	185	190	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 185 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	21	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.26	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.054	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.008	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P =±5 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_{J(max)}$, is not exceeded.

[2]Percentage of I_P, with I_P = 5 A. Output filtered.

x20A PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–20	–	20	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	96	100	104	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 100 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	11	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.34	–	mV/°C
		T_A = 25°C to 150°C	–	–0.07	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.017	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.004	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P =±20 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.

[2]Percentage of I_P, with I_P = 20 A. Output filtered.

x30A PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

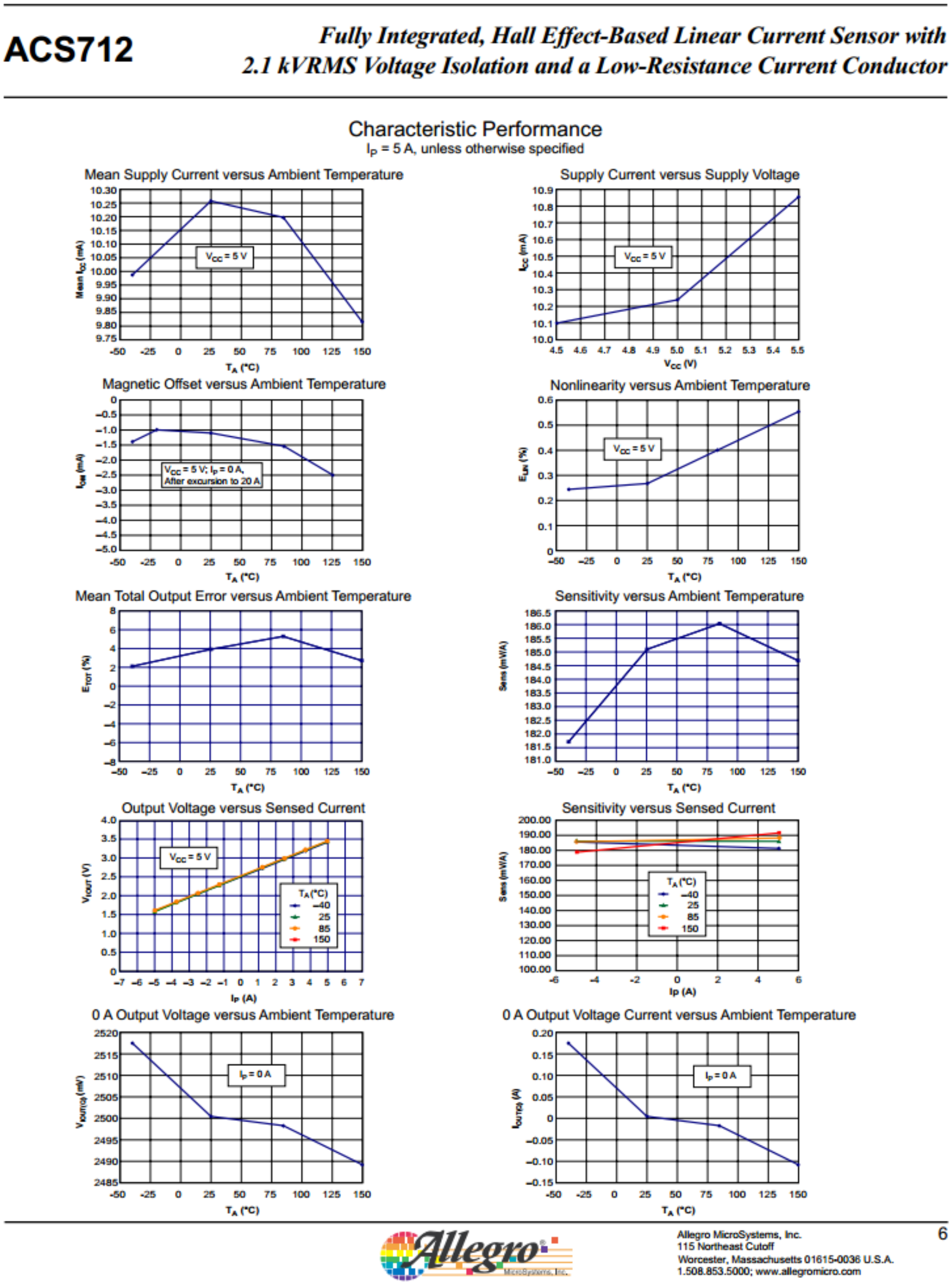
Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–30	–	30	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	64	66	68	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 66 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	7	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.35	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.007	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.002	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±30 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.

[2]Percentage of I_P, with I_P = 30 A. Output filtered.

Allegro MicroSystems, Inc.
115 Northeast Cutoff
Worcester, Massachusetts 01615-0036 U.S.A.
1.508.853.5000; www.allegromicro.com

5



Characteristic Performance

I_P = 5 A, unless otherwise specified

Mean Supply Current versus Ambient Temperature

Supply Current versus Supply Voltage

Magnetic Offset versus Ambient Temperature

Nonlinearity versus Ambient Temperature

Mean Total Output Error versus Ambient Temperature

Sensitivity versus Ambient Temperature

Output Voltage versus Sensed Current

Sensitivity versus Sensed Current

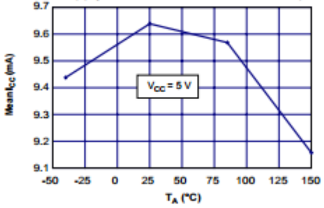
0 A Output Voltage versus Ambient Temperature

0 A Output Voltage Current versus Ambient Temperature

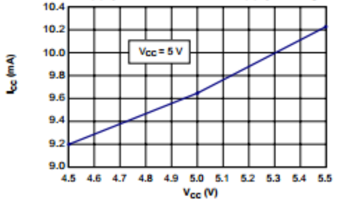
Characteristic Performance

I_P = 20 A, unless otherwise specified

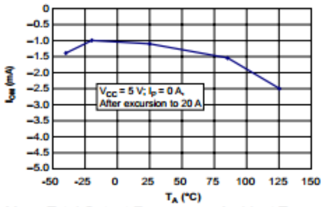
Mean Supply Current versus Ambient Temperature



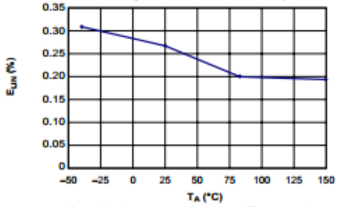
Supply Current versus Supply Voltage



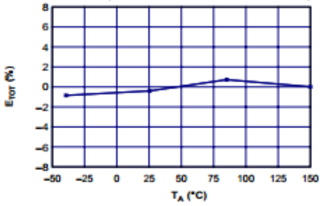
Magnetic Offset versus Ambient Temperature



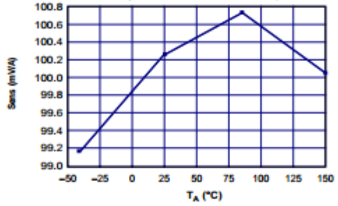
Nonlinearity versus Ambient Temperature



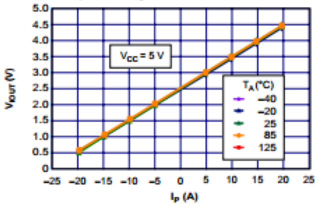
Mean Total Output Error versus Ambient Temperature



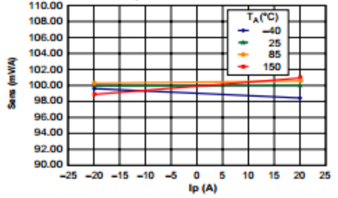
Sensitivity versus Ambient Temperature



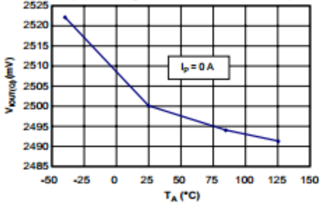
Output Voltage versus Sensed Current



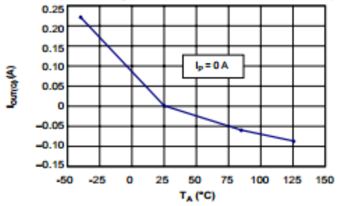
Sensitivity versus Sensed Current



0 A Output Voltage versus Ambient Temperature



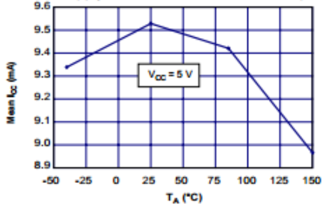
0 A Output Voltage Current versus Ambient Temperature



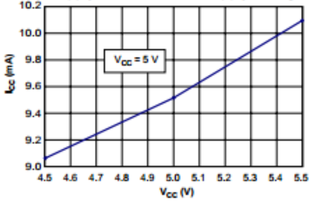
Characteristic Performance

I_P = 30 A, unless otherwise specified

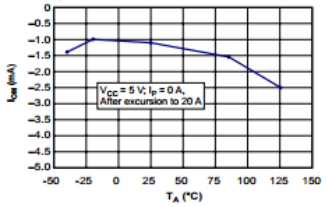
Mean Supply Current versus Ambient Temperature



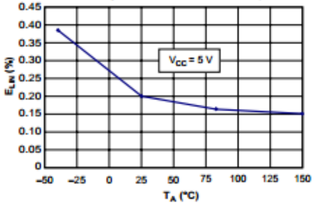
Supply Current versus Supply Voltage



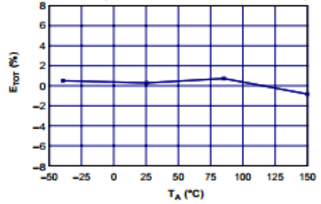
Magnetic Offset versus Ambient Temperature



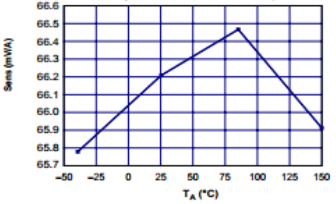
Nonlinearity versus Ambient Temperature



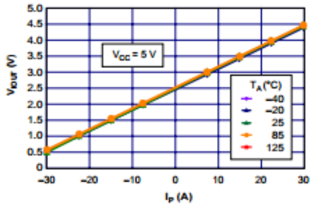
Mean Total Output Error versus Ambient Temperature



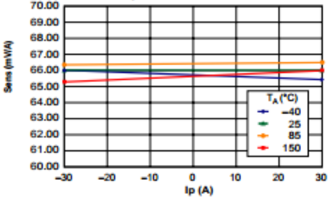
Sensitivity versus Ambient Temperature



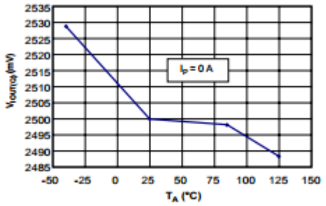
Output Voltage versus Sensed Current



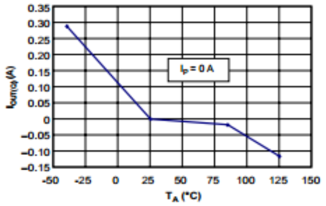
Sensitivity versus Sensed Current



0 A Output Voltage versus Ambient Temperature



0 A Output Voltage Current versus Ambient Temperature



Definitions of Accuracy Characteristics

Sensitivity (Sens). The change in sensor output in response to a 1 A change through the primary conductor. The sensitivity is the product of the magnetic circuit sensitivity (G/A) and the linear IC amplifier gain (mV/G). The linear IC amplifier gain is programmed at the factory to optimize the sensitivity (mV/A) for the full-scale current of the device.

Noise (V_{NOISE}). The product of the linear IC amplifier gain (mV/G) and the noise floor for the Allegro Hall effect linear IC (≈1 G). The noise floor is derived from the thermal and shot noise observed in Hall elements. Dividing the noise (mV) by the sensitivity (mV/A) provides the smallest current that the device is able to resolve.

Linearity (E_{LIN}). The degree to which the voltage output from the sensor varies in direct proportion to the primary current through its full-scale amplitude. Nonlinearity in the output can be attributed to the saturation of the flux concentrator approaching the full-scale current. The following equation is used to derive the linearity:

$$100\left\{1-\left[\frac{\Delta\text{ gain}\times\%\text{ sat }(V_{\text{IOUT\_full-scale amperes}}-V_{\text{IOUT(Q)}})}{2\,(V_{\text{IOUT\_half-scale amperes}}-V_{\text{IOUT(Q)}})}\right]\right\}$$

where $V_{\text{IOUT\_full-scale amperes}}$ = the output voltage (V) when the sensed current approximates full-scale $\pm I_P$.

Symmetry (E_{SYM}). The degree to which the absolute voltage output from the sensor varies in proportion to either a positive or negative full-scale primary current. The following formula is used to derive symmetry:

$$100\left(\frac{V_{\text{IOUT\_+ full-scale amperes}}-V_{\text{IOUT(Q)}}}{V_{\text{IOUT(Q)}}-V_{\text{IOUT\_–full-scale amperes}}}\right)$$

Quiescent output voltage ($V_{IOUT(Q)}$). The output of the sensor when the primary current is zero. For a unipolar supply voltage, it nominally remains at $V_{CC}/2$. Thus, V_{CC} = 5 V translates into $V_{IOUT(Q)}$ = 2.5 V. Variation in $V_{IOUT(Q)}$ can be attributed to the resolution of the Allegro linear IC quiescent voltage trim and thermal drift.

Electrical offset voltage (V_{OE}). The deviation of the device output from its ideal quiescent value of $V_{CC}/2$ due to nonmagnetic causes. To convert this voltage to amperes, divide by the device sensitivity, Sens.

Accuracy (E_{TOT}). The accuracy represents the maximum deviation of the actual output from its ideal value. This is also known as the total ouput error. The accuracy is illustrated graphically in the output voltage versus current chart at right.

Accuracy is divided into four areas:

- **0 A at 25°C.** Accuracy of sensing zero current flow at 25°C, without the effects of temperature.
- **0 A over Δ temperature.** Accuracy of sensing zero current flow including temperature effects.
- **Full-scale current at 25°C.** Accuracy of sensing the full-scale current at 25°C, without the effects of temperature.
- **Full-scale current over Δ temperature.** Accuracy of sensing full-scale current flow including temperature effects.

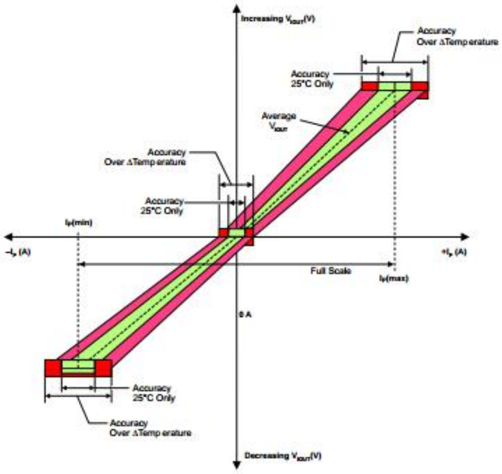
Ratiometry. The ratiometric feature means that its 0 A output, $V_{IOUT(Q)}$, (nominally equal to $V_{CC}/2$) and sensitivity, Sens, are proportional to its supply voltage, V_{CC}. The following formula is used to derive the ratiometric change in 0 A output voltage, $\Delta V_{IOUT(Q)RAT}$ (%).

$$100\left(\frac{V_{\text{IOUT(Q)VCC}}\,/\,V_{\text{IOUT(Q)5V}}}{V_{CC}\,/\,5\text{ V}}\right)$$

The ratiometric change in sensitivity, ΔSens_{RAT} (%), is defined as:

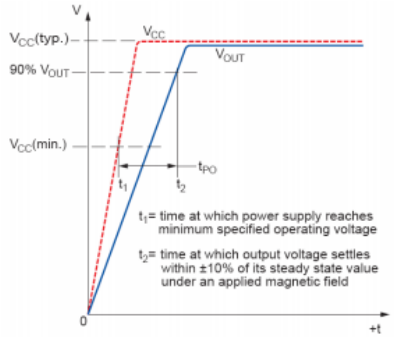
$$100\left(\frac{Sens_{VCC}\,/\,Sens_{5V}}{V_{CC}\,/\,5\text{ V}}\right)$$

Output Voltage versus Sensed Current
Accuracy at 0 A and at Full-Scale Current



Definitions of Dynamic Response Characteristics

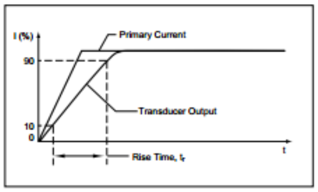
Power-On Time (t_{PO}). When the supply is ramped to its operating voltage, the device requires a finite time to power its internal components before responding to an input magnetic field. Power-On Time, t_{PO} , is defined as the time it takes for the output voltage to settle within ±10% of its steady state value under an applied magnetic field, after the power supply has reached its minimum specified operating voltage, V_{CC}(min), as shown in the chart at right.



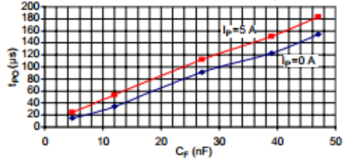
t_1= time at which power supply reaches minimum specified operating voltage

t_2= time at which output voltage settles within ±10% of its steady state value under an applied magnetic field

Rise time (t_r). The time interval between a) when the sensor reaches 10% of its full scale value, and b) when it reaches 90% of its full scale value. The rise time to a step response is used to derive the bandwidth of the current sensor, in which $f(-3\text{ dB}) = 0.35/t_r$. Both t_r and $t_{RESPONSE}$ are detrimentally affected by eddy current losses observed in the conductive IC ground plane.

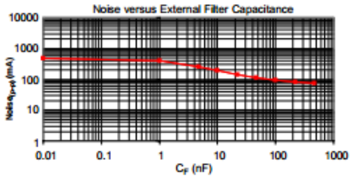


Power on Time versus External Filter Capacitance



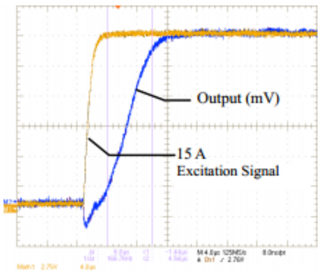
Noise vs. Filter Cap

Noise versus External Filter Capacitance

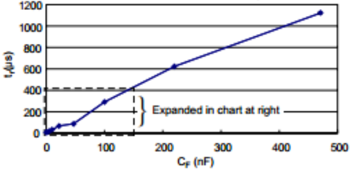


Step Response

T_A=25°C

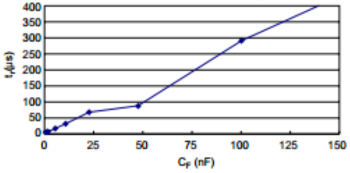


Rise Time versus External Filter Capacitance



C_F (nF)	t_r (µs)
0	6.6
1	7.7
4.7	17.4
10	32.1
22	68.2
47	88.2
100	291.3
220	623.0
470	1120.0

Rise Time versus External Filter Capacitance

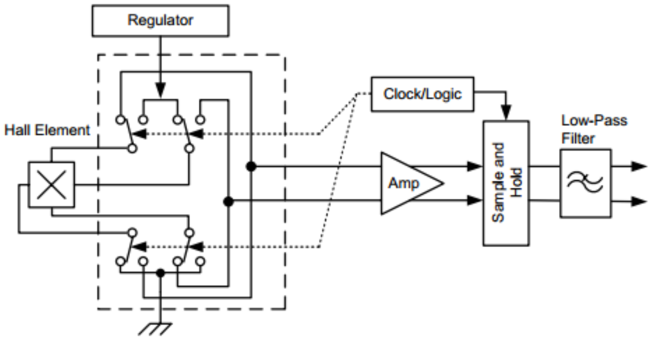


Chopper Stabilization Technique

Chopper Stabilization is an innovative circuit technique that is used to minimize the offset voltage of a Hall element and an associated on-chip amplifier. Allegro patented a Chopper Stabilization technique that nearly eliminates Hall IC output drift induced by temperature or package stress effects. This offset reduction technique is based on a signal modulation-demodulation process. Modulation is used to separate the undesired dc offset signal from the magnetically induced signal in the frequency domain. Then, using a low-pass filter, the modulated dc offset is suppressed while the magnetically induced signal passes through the filter.

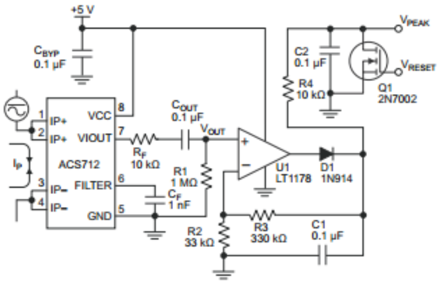
As a result of this chopper stabilization approach, the output voltage from the Hall IC is desensitized to the effects of temperature and mechanical stress. This technique produces devices that have an extremely stable Electrical Offset Voltage, are immune to thermal stress, and have precise recoverability after temperature cycling.

This technique is made possible through the use of a BiCMOS process that allows the use of low-offset and low-noise amplifiers in combination with high-density logic integration and sample and hold circuits.

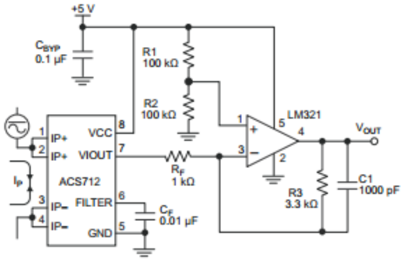


Concept of Chopper Stabilization Technique

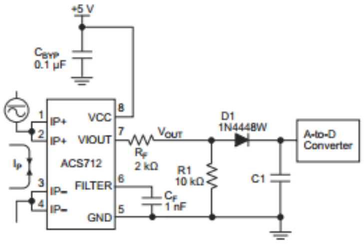
Typical Applications



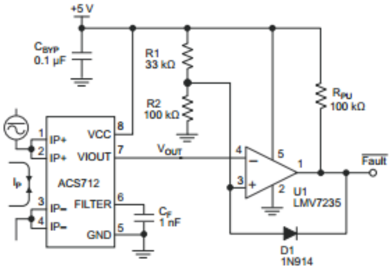
Application 2. Peak Detecting Circuit



Application 3. This configuration increases gain to 610 mV/A (tested using the ACS712ELC-05A).



Application 4. Rectified Output. 3.3 V scaling and rectification application for A-to-D converters. Replaces current transformer solutions with simpler ACS circuit. C1 is a function of the load resistance and filtering desired. R1 can be omitted if the full range is desired.



Application 5. 10 A Overcurrent Fault Latch. Fault threshold set by R1 and R2. This circuit latches an overcurrent fault and holds it until the 5 V rail is powered down.

Improving Sensing System Accuracy Using the FILTER Pin

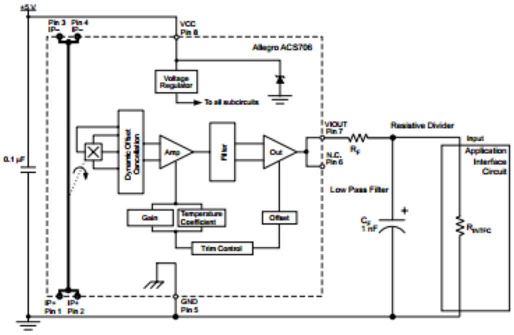
In low-frequency sensing applications, it is often advantageous to add a simple RC filter to the output of the sensor. Such a low-pass filter improves the signal-to-noise ratio, and therefore the resolution, of the sensor output signal. However, the addition of an RC filter to the output of a sensor IC can result in undesirable sensor output attenuation — even for dc signals.

Signal attenuation, ΔV_{ATT}, is a result of the resistive divider effect between the resistance of the external filter, R_F (see Application 6), and the input impedance and resistance of the customer interface circuit, R_{INTFC}. The transfer function of this resistive divider is given by:

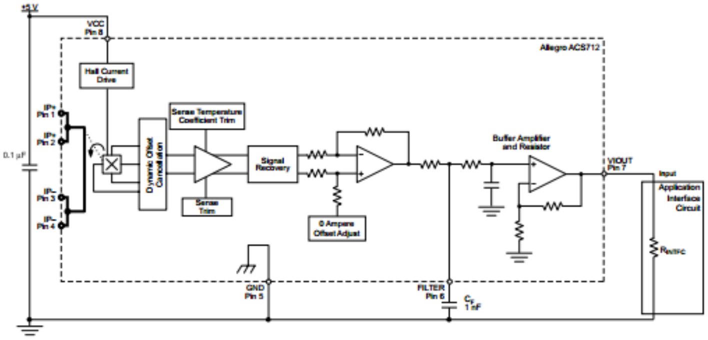
$$\Delta V_{ATT} = V_{IOUT}\left(\frac{R_{INTFC}}{R_F + R_{INTFC}}\right) .$$

Even if R_F and R_{INTFC} are designed to match, the two individual resistance values will most likely drift by different amounts over temperature. Therefore, signal attenuation will vary as a function of temperature. Note that, in many cases, the input impedance, R_{INTFC}, of a typical analog-to-digital converter (ADC) can be as low as 10 kΩ.

The ACS712 contains an internal resistor, a FILTER pin connection to the printed circuit board, and an internal buffer amplifier. With this circuit architecture, users can implement a simple RC filter via the addition of a capacitor, C_F (see Application 7) from the FILTER pin to ground. The buffer amplifier inside of the ACS712 (located after the internal resistor and FILTER pin connection) eliminates the attenuation caused by the resistive divider effect described in the equation for ΔV_{ATT}. Therefore, the ACS712 device is ideal for use in high-accuracy applications that cannot afford the signal attenuation associated with the use of an external RC low-pass filter.

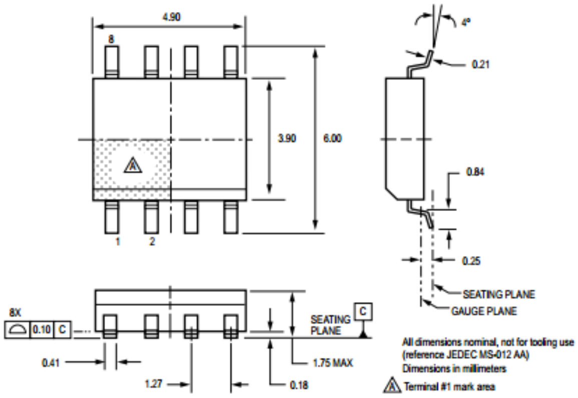


Application 6. When a low pass filter is constructed externally to a standard Hall effect device, a resistive divider may exist between the filter resistor, R_F, and the resistance of the customer interface circuit, R_{INTFC}. This resistive divider will cause excessive attenuation, as given by the transfer function for ΔV_{ATT}.



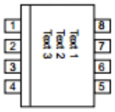
Application 7. Using the FILTER pin provided on the ACS712 eliminates the attenuation effects of the resistor divider between R_F and R_{INTFC}, shown in Application 6.

Package LC, 8-pin SOIC



Package Branding

Two alternative patterns are used



ACS712T *RLCPPP* *YYWWA*	ACS	Allegro Current Sensor
	712	Device family number
	T	Indicator of 100% matte tin leadframe plating
	R	Operating ambient temperature range code
	LC	Package type designator
	PPP	Primary sensed current
	YY	Date code: Calendar year (last two digits)
	WW	Date code: Calendar week
	A	Date code: Shift code

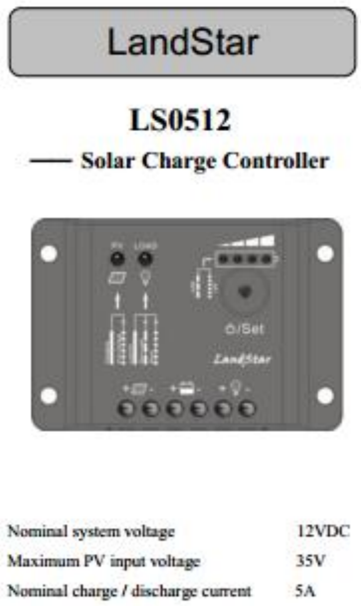
ACS712T *RLCPPP* *L...L* *YYWW*	ACS	Allegro Current Sensor
	712	Device family number
	T	Indicator of 100% matte tin leadframe plating
	R	Operating ambient temperature range code
	LC	Package type designator
	PPP	Primary sensed current
	L...L	Lot code
	YY	Date code: Calendar year (last two digits)
	WW	Date code: Calendar week

The products described herein are manufactured under one or more of the following U.S. patents: 5,045,920; 5,264,783; 5,442,283; 5,389,889; 5,581,179; 5,517,112; 5,619,137; 5,621,319; 5,650,719; 5,686,894; 5,694,038; 5,729,130; 5,917,320; and other patents pending.

For the latest version of this document, visit our website:

www.allegromicro.com

Appendix B – LS0512 Solar Charger Controller Datasheet

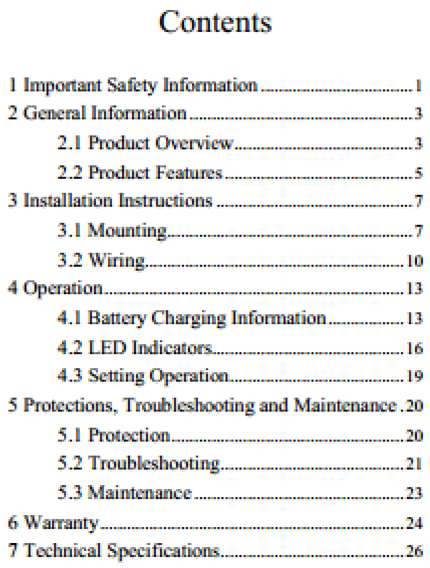


LandStar

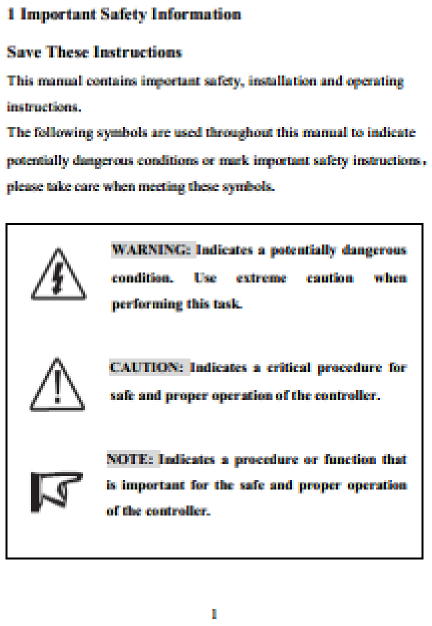
LS0512

—— Solar Charge Controller

Nominal system voltage	12VDC
Maximum PV input voltage	35V
Nominal charge / discharge current	5A



Contents



1 Important Safety Information

Save These Instructions

This manual contains important safety, installation and operating instructions.

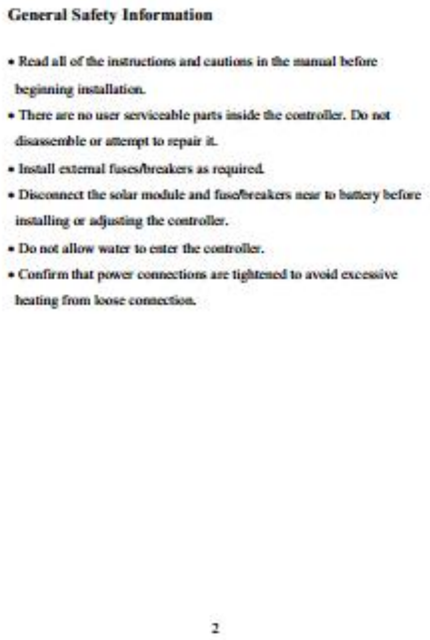
The following symbols are used throughout this manual to indicate potentially dangerous conditions or mark important safety instructions, please take care when meeting these symbols.

WARNING: Indicates a potentially dangerous condition. Use extreme caution when performing this task.

CAUTION: Indicates a critical procedure for safe and proper operation of the controller.

NOTE: Indicates a procedure or function that is important for the safe and proper operation of the controller.

1



General Safety Information

- Read all of the instructions and cautions in the manual before beginning installation.
- There are no user serviceable parts inside the controller. Do not disassemble or attempt to repair it.
- Install external fuses/breakers as required.
- Disconnect the solar module and fuse/breakers near to battery before installing or adjusting the controller.
- Do not allow water to enter the controller.
- Confirm that power connections are tightened to avoid excessive heating from loose connection.

2

2 General Information

2.1 Product Overview

Thank you for selecting LandStar series solar charge controller that adopts the most advanced digital technique and operates fully automatically. The Pulse Width Modulation (PWM) battery charging can greatly increase the lifetime of battery. It has various unique functions and quite easy to use, such as:

- High efficient Series PWM charging, increase the battery lifetime and improve the solar system performance.
- Use MOSFET as electronic switch, without any mechanical switch
- LED indicators indicate battery voltage state.
- Adopt temperature compensation, correct the charging and discharging parameters automatically and improve the battery lifetime.
- Electronic protection: over charging, over discharging, overload, and short circuit.
- Reverse protection for battery.

The controller is for off-grid solar system, especially in solar light system, and protects the battery from being over charged by the solar module and over discharged by the loads. The charging process has been optimized for long battery life and improved system performance. The comprehensive self-diagnostics and electronic protection functions can prevent damage from installation mistakes or system faults.

Though the controller is easy to operate and use, please take your time to read this manual and become familiar with it. This will help you make full use of all the functions and improve your solar PV system.

2.2 Product Features

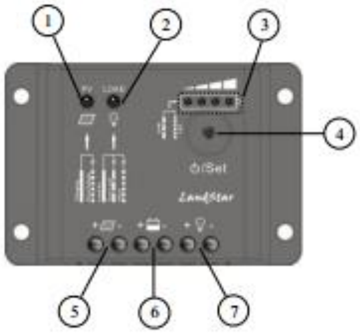


Figure 2-1 LandStar characteristics

1 –Charging status LED indicator

An LED indicator that shows charging status and also indicates when battery voltage is higher than over voltage disconnect voltage.

2 –Load status LED indicator

An LED indicator that shows load status

3 –Battery voltage LED indicators

Four LED indicators indicating battery voltages .

4 –Setting button

Control the load ON/OFF and select the battery type

5 –Solar Module Terminals

Connect solar modules.

6 –Battery Terminals

Connect batteries.

7 –Load Terminals

Connect loads.

3 Installation Instructions

3.1 Mounting

- Read through the entire installation section first before beginning installation.
- Be very careful when working with batteries. Wear eye protection. Have fresh water available to wash and clean any contact with battery acid.
- Uses insulated tools and avoid placing metal objects near the batteries.
- Explosive battery gasses may be present during charging. Be certain there is sufficient ventilation to release the gasses.
- Avoid direct sunlight and do not install in locations where water can enter the controller.
- Loose power connections and/or corroded wires may result in resistive connections that melt wire insulation, burn surrounding materials, or even cause fire. Ensure tight connections and use cable clamps to secure cables and prevent them from swaying in mobile applications.
- Use with Gel, Sealed or Flooded batteries only.
- Battery connection may be wired to one battery or a bank of batteries. The following instructions refer to a singular battery, but it is implied that the battery connection can be made to either one battery or a group of batteries in a battery bank.
- Select the system cables according to 3A/mm^2 current density.

NOTE: When mounting the controller, ensure free air through the controller heat sink fins. There should be at least 6 inches (150 mm) of clearance above and below the controller to allow for cooling. If mounted in an enclosure, ventilation is highly recommended.

WARNING: Risk of explosion! Never install the controller in a sealed enclose with flooded batteries! Do not install in a confined area where battery gassed can accumulate.

Step 1: Choose Mounting Location

Locate the controller on a vertical surface protected from direct sun, high temperature, and water. And make sure good ventilation.

Step 2: Check for clearance

Place the controller in the location where it will be mounted. Verify that there is sufficient room to run wires and that there is sufficient room above and below the controller for air flow.

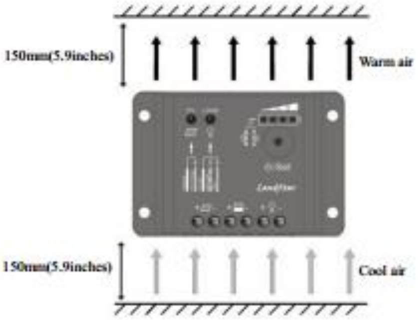


Figure 3-1 Mounting and cooling

Step 3: Mark Holes

Use a pencil or pen to mark the four (4) mounting hole locations on the mounting surface.

Step 4: Drill Holes

Remove the controller and drill 4 holes in the marked locations.

Step 5: Secure Controller

Place the controller on the surface and align the mounting holes with the drilled holes in step 4.

Secure the controller in place using the mounting screws.

3.2 Wiring

NOTE: A recommended connection order has been provided for maximum safety during installation.

NOTE: The controller is a common positive ground controller.

CAUTION: Don't connect the loads with surge power exceeding the ratings of the controller.

CAUTION: For mobile applications, be sure to secure all wiring. Unsecured cables create loose and resistive connections which may lead to excessive heating and/or fire.

WARNING: Risk of explosion or fire! Never short circuit battery positive (+) and negative (-) or cables.

WARNING: Risk of electric shock! Exercise caution when handling solar wiring. The solar module(s) high voltage output can cause severe shock or injury. Be careful operation when **installing solar wiring.**

Before battery is connected, make sure that battery voltage is greater than 6V so as to start up the controller.

The load should be DC applicant with the same rated voltage as battery's. Controller offers power to loads through the battery voltage.

It is recommended that no less than 2 times rated current fuse is connected with battery and load.

Step 1: Wiring

The recommended connection order has been provided as Figure3-2 indicated. Be sure the negative and positive polarity connection is correct and all terminals are tightened.

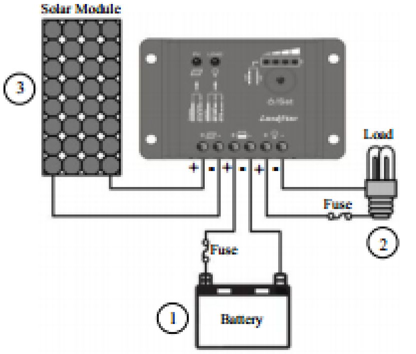


Figure 3-2 System wiring review

Step 2: Confirm power on

When battery power is applied and the controller starts up, the battery LED indicators will be on. If the controller doesn't start up, or the battery LED error exists, please refer to section 5 for troubleshooting.

4 Operation

4.1 Battery Charging Information

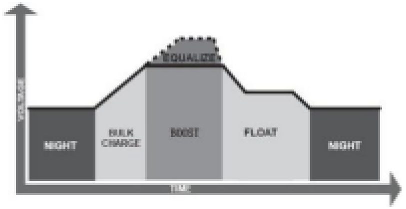


Figure 4-1 PWM Charging mode

·Bulk Charge

In this stage, the battery voltage has not yet reached boost voltage and 100% of available solar power is used to charge the battery.

·Boost Charge

When the battery has recharged to the Boost voltage setpoint, constant-current regulation is used to prevent heating and excessive battery gassing. The Boost stage remains 120 minutes and then goes to Float Charge.

·Float Charge

After the battery is fully charged in Boost voltage stage, the controller reduces the battery voltage to Float voltage set point. When the battery is fully recharged, there will be no more chemical reactions and all the charge current transmits into heat and gas at this time. Then the controller reduces the voltage to the floating stage, charging with a smaller voltage and current. It will reduce the temperature of battery and prevent the gassing, also charging the battery slightly at the same time. The purpose of Float stage is to offset the power consumption caused by self consumption and small loads in the whole system, while maintaining full battery storage capacity.

In Float stage, loads can continue to draw power from the battery. In the event that the system load(s) exceed the solar charge current, the controller will no longer be able to maintain the battery at the Float setpoint. Should the battery voltage remains below the boost reconnect charging voltage, the controller will exit Float stage and return to Bulk charge.

·Equalize Charge

WARNING: Risk of explosion!

Equalizing flooded battery can produce explosive gases, so well ventilation of battery box is necessary.

NOTE: Equipment damage!

Equalization may increase battery voltage to the level damaging to sensitive DC loads. Ensure that all load allowable input voltages are greater than the equalizing charging set point voltage.

NOTE: Equipment damage!

Over-charging and excessive gas precipitation may damage the battery plates and activate material shedding on them. Too high an equalizing charge or for too long may cause damage. Please carefully review the specific requirements of the battery used in the system.

Certain types of batteries benefit from periodic equalizing charge, which can stir the electrolyte, balance battery voltage and complete chemical reaction. Equalizing charge increases the battery voltage, higher than the standard complement voltage, which gasifies the battery electrolyte.

If the battery is over discharged, the solar controller will automatically turn to equalize charging stage, and the equalize stage remains 120mins. Equalize charge and boost charge are not carried out constantly in a full charge process to avoid too much gas precipitation or overheating of battery.

4.2 LED Indicators

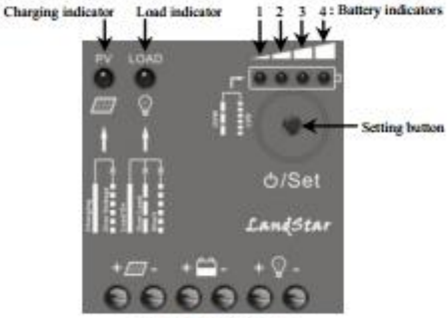


Figure 4-2 LED indicators

● Charging status indicator

ON whenever sunlight is available for battery charging,

FAST FLASHING when battery over voltage.

Please refer to section 5 for troubleshooting.

Charging status LED indicator Table 4-1

Indicator	Charging Status
On Solid	Charging
Fast Flashing	Battery over voltage

●Battery status indicator

LED1 SLOWLY FLASHING when battery under voltage

LED1 FAST FLASHING when battery over discharged

Please see the instruction of battery voltage indicating in the table 4-2.

Please refer to section 5 for troubleshooting.

Battery LED indicator Table 4-2

LED1	LED 2	LED 3	LED 4	Battery Status
SLOWLY FLASHING	×	×	×	Under voltage
FAST FLASHING	×	×	×	Over discharged
Battery LED indicator status during voltage is up				
O	O	×	×	>12.8V
O	O	O	×	>13.4V
O	O	O	O	>14.1V
Battery LED indicator status during voltage is down				
O	O	O	×	<13.4V
O	O	×	×	<12.8V
O	×	×	×	<12.4V

"o"LED indicator on "×"LED indicator off

● Load status indicator:

Load indicator ON when load output is in normal. When the load amp is 1.25times of rated current for 60 seconds, or the load amp is 1.5 times of rated current for 5 seconds (overload), Load indicator SLOWLY FLASHING. When the load is short circuit, Load indicator will FAST FLASHING. Please refer to section 5 for trouble shooting.

Load status LED indicator Table 4-3

Indicator	Load status
On solid	ON
On solid	OFF
SLOWLY FLASHING	Overload
FAST FLASHING	Short Circuit

4.3 Setting Operation

● Load Work Mode Setting

When the controller is powered on, press the setting button to control the load output. Press the button once, the ON/OFF status will be changed corresponding.

● Battery Type Setting

Press the setting button for more than 5 seconds, battery indicator LED1, LED2, LED3 will be flashing correspondingly. Then press the setting button to choose Sealed, Gel, and Flooded battery type. The setting is finished till the digital tube stop flashing.

Battery type selection Table4-4

1	2	3	Battery type
O	×	×	Sealed lead acid battery
O	O	×	Gel battery
O	O	O	Flooded battery

"o"LED indicator on "×"LED indicator off

5 Protection, Troubleshooting and Maintenance

5.1 Protection

·Load Overload

If the load current exceeds the maximum load current rating, the controller will disconnect the load. Overloading must be cleared up through reapply power or pressing the setting button.

·Load Short Circuit

Fully protected against load wiring short-circuit. After one automatic load reconnect attempt, the fault must be cleared by reapply power or pressing the setting button.

·Battery Reverse Polarity

Fully protection against battery reverse polarity, no damage to the controller will result. Correct the miswire to resume normal operation.

·Damaged Local Temperature Sensor

If the temperature sensor short-circuited or damaged, the controller will be charging or discharging at the default temperature 25℃ to prevent the battery damaged from overcharging or over discharged.

·High Voltage Transients

PV is protected against high voltage transients. In lightning prone areas, additional external suppression is recommended.

5.2 Troubleshooting

Trouble Shooting Table 5-1

Faults	Possible reasons	Troubleshooting
Charging LED indicator off during daytime when sunshine falls on PV modules properly.	PV array disconnection	Check that PV and battery wire connections are correct and tight.
charging LED indicator fast flashing	Battery voltage higher than over voltage disconnect voltage(OVD)	Check if battery voltage over high. Disconnect the solar module
Battery LED1 indicator SLOWLY FLASHING	Battery under voltage	When load output is normal, LED status will return to ON automatically when fully charged.
Battery LED1 indicator FAST FLASHING.	Battery over discharged	When the controller cut off the output automatically, LED status will return to ON automatically when fully charged.
Load LED indicator SLOWLY FLASHING	Over load	Please reduce the load and press the button once, the controller will resume to work after 3s
Load LED indicator FAST FLASHING	Short circuit	when the first short-circuit occurs, the controller will automatically resume to work after 10s; when a second short-circuit occurs, press the button, the controller will resume to work after 3s

Notes: No LED indicator.
Measure battery voltage with multimeter.
Min.6V can start up the controller.

Notes: No charging status LED indicator with normal connection. Measure the input voltage of solar module, the input voltage must be higher than battery voltage!

5.3 Maintenance

The following inspections and maintenance tasks are recommended at least two times per year for best controller performance.

- Check that the controller is securely mounted in a clean and dry environment.
- Check that the air flow and ventilation around the controller is not blocked. Clear all dirt or fragments on the heat sink.
- Check all the naked wires to make sure insulation is not damaged for serious solarization, frictional wear, dryness, insects or rats etc. Maintain or replace the wires if necessary.
- Tighten all the terminals. Inspect for loose, broken, or burnt wire connections.
- Check and confirm that LED digital tube is consistent with required. Pay attention to any troubleshooting or error indication .Take necessary corrective action.
- Confirm that all the system components are ground connected tightly and correctly.

- Confirm that all the terminals have no corrosion, insulation damaged, high temperature or burnt/discolored sign, tighten terminal screws to the suggested torque.
- Inspect for dirt, insects and corrosion, and clear up.
- Check and confirm that lightning arrester is in good condition. Replace a new one in time to avoid damaging of the controller and even other equipments.

Notes: Dangerous with electric shock!
Make sure that all power source of controller is cut off when operate above processes, and then make inspection or other operations!

6 Warranty

The LandStar charge controller is warranted to be free from defects for a period of TWO (2) years from the date of shipment to the original end user. We will, at its option, repair or replace any such defective products.

• Claim procedure:

Before requesting warranty service, check the Operation Manual to be certain that there is a problem with the controller. Return the defective product to us with shipping charges prepaid if problem cannot be solved. Provide proof of date and place of purchase. To obtain rapid service under this warranty, the returned products must include the model, serial number and detailed reason for the failure, the module type and size, type of batteries and system loads. This information is critical to a rapid disposition of your warranty claim.

•This warranty does not apply under the following conditions:

1. Damage by accident, negligence, abuse or improper use.
2. PV or load current exceeding the ratings of product.
3. Unauthorized product modification or attempted repair
4. Damaged occurring during shipment.
5. Damage results from acts of nature such as lightning, weather extremes.
6. Irreclaimable mechanical damage.

7 Technical specifications

Electrical Parameters Table 7-1

Description	Parameter
Nominal System Voltage	12V
Max. batt. Volt. to the controller	16V
Rated Battery Current	5A
Charge Circuit Voltage Drop	≤0.26V
Discharge Circuit Voltage Drop	≤0.15V
Self-consumption	≤6mA

Temperature Compensation Coefficient Table7-2

Description	Parameter
Temperature Compensation Coefficient(TEMPCO)*	-30mV/℃/12V（25℃ ref）

*** Compensation of equalize, boost, float and low voltage disconnect voltage**

Battery Voltage Parameters (temperature at 25℃)　　Table 7-3

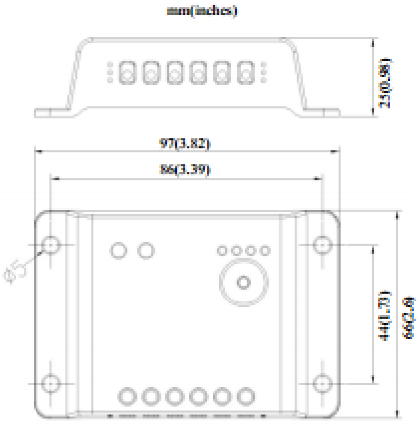
Charging Parameters			
Battery charging setting	Gel	Sealed	Flooded
Over Voltage Disconnect Voltage	16V	16V	16V
Charging Limit Voltage	15.5V	15.5V	15.5V
Over Voltage Reconnect Voltage	15V	15V	15V
Equalize Charging Voltage	-------	14.6V	14.8V
Boost Charging Voltage	14.2V	14.4V	14.6V
Float Charging Voltage	13.8V	13.8V	13.8V
Boost Reconnect Charging Voltage	13.2V	13.2V	13.2V
Low Voltage Reconnect Voltage	12.6V	12.6V	12.6V
Under Voltage Warning Reconnect Voltage	12.2V	12.2V	12.2V
Under Voltage Warning Voltage	12V	12V	12V
Low Voltage Disconnect Voltage	11.1V	11.1V	11.1V
Discharging Limit Voltage	10.8V	10.8V	10.8V
Equalize Duration	-------	2 hours	2 hours
Boost Duration	2 hours	2 hours	2 hours

Environmental parameters　　Table 7-4

Environmental parameters	Parameter
Working temperature	-35℃ to +55℃
Storage temperature	-35℃to +80℃
Humidity	10%-90% NC
Enclosure	IP30

Mechanical Parameters　　Table 7-5

Mechanical Parameter	Parameter
Overall dimension	97(3.82)x66(2.6)x25(0.98) mm/inches
Mounting dimension	86(3.39) x 44(1.73) mm/inches
Mounting hole size	Φ5
Terminal	2.5mm²
Net weight	0.05kg



Dimensions

Final interpretation right of the manual belongs to our company.

Any changes without prior notice!

Version number: V6.0

BEIJING EPSOLAR TECHNOLOGY CO., LTD.

Tel：010-82894112 / 82894962

Fax：010-82894882

E-mail：info@epsolarpv.com

Website: www.epsolarpv.com

Appendix C – Shield LCD User’s Manual

Cytron Technologies

Shield-LCD
User’s Manual

V1.0

July 2011

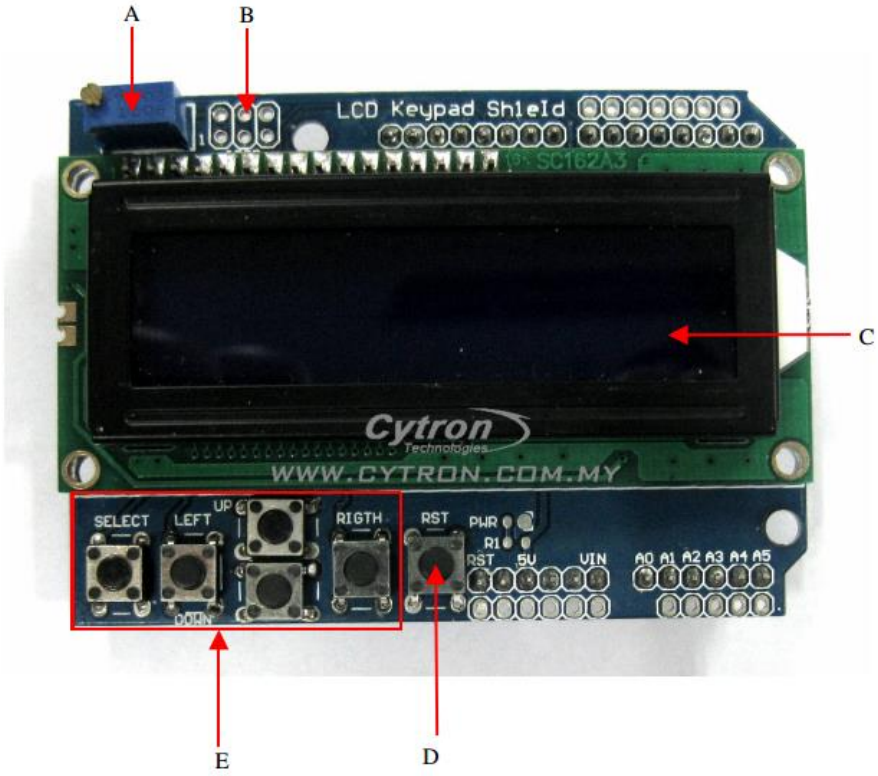
1. INTRODUCTION

The *LCD Keypad shield* is developed for Arduino compatible boards, to provide a user-friendly interface that allows users to go through the menu, make selections etc. It consists of a 1602 white character blue backlight LCD. The keypad consists of 5 keys — select, up, right, down and left. To save the digital IO pins, the keypad interface uses only one ADC channel. The key value is read through a 5 stage voltage divider.

Features:

- Operate at 5V
- Uses Arduino LCD4Bit library
- Plug and Use with Arduino main board, no solder or fly-wiring needed.
- 2x16 LCD, White character, Blue backlight
- 6 push buttons

2. BOARD LAYOUT



Label	Function	Label	Function
A	LCD Contrast potentiometer	**D**	Reset Button
B	ICSP	**E**	Push button connect to Analog Input Pin0
C	LCD Display		

3. PIN ALLOCATION

Pin	Function
Analog 0	Button (select, up, right, down and left)
Digital 4	DB4
Digital 5	DB5
Digital 6	DB6
Digital 7	DB7
Digital 8	RS (Data or Signal Display Selection)
Digital 9	Enable
Digital 10	Backlight Control

4. WARRANTY

- Product warranty is valid for 6 months.
- Warranty only applies to manufacturing defect.
- Damage caused by mis-use is not covered under warranty.
- Warranty does not cover freight cost for both ways.

Prepared by
Cytron Technologies Sdn. Bhd.
19, Jalan Kebudayaan 1A,
Taman Universiti,
81300 Skudai,
Johor, Malaysia.

Tel: *+607-521 3178*
Fax: *+607-521 1861*

URL: www.cytron.com.my
Email: support@cytron.com.my
sales@cytron.com.my