Cal Poly Rose Float Electric Vehicle

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1. Variable Frequency Drive (VFD)- A device which controls the frequency of the power supplied to an AC motor, this is used to control the speed of the motor.

2. Gantt Chart- A project management tool, which sets up a timeline for project goals.

3. Quality Function Deployment (QFD)- A method for taking customer needs in lay-terms and transforming them into engineering specifications.

4. Mechatronics- a multidisciplinary engineering field which combines mechanical and electrical knowledge.

5. IGBT- (insulated gate bipolar transistor) a device which rapidly switches on and off supply power to create a pseudo waveform. They are fast switching and highly efficient.

ABSTRACT

(1) Background:

The Cal Poly Rose Float is currently powered by a pair of V-8 internal combustion engines. This is the second project in a three phase effort to replace the existing drive engine with electric motor powered by a DC bus. The main goal of this phase of the project is to get the motor selected in phase one spinning.

(2) Results:

Originally, the project involved programming a microcontroller to achieve motor control. The decision was made, early on, to approach this task in a different manner due to the team's minimal background in programming and mechatronics. The team decided to purchase and implement a commercially available variable frequency drive to get the motor spinning, and to offer a more sophisticated level of control. After extensive research, planning, purchasing of required components, and connectivity considerations, sufficient motor control was achieved.

(3) Conclusion:

The selection of a variable frequency drive to gain motor control was successful, and the goals of phase 2 in the Cal Poly electric vehicle project were accomplished. The project is ready to enter the next phase which is to be completed by another team of students.

I. INTRODUCTION

Each year, Cal Poly San Luis Obispo students, in a joint effort with students from Cal Poly Pomona, design and build a rose float to be entered into the Tournament of Roses Parade. This float is built entirely by volunteers including university students, and the complex process that goes into completing a rose float takes a full year. Cal Poly Rose Float illustrates the school's "Learn by Doing" motto, and shows the excellence which can be achieved by Cal Poly students.

The entire project is divided into three phases with the goal of converting the float's current propane engine into a fully electric drivetrain. This new float will be more environmentally friendly and will develop Cal Poly's electric vehicle knowledge. A basic outline of the three phase senior project is provided below. This senior project will begin in phase 2, and more information on the objectives can be found in the following sections.

PHASE 1: Perform analysis of all necessary components of the float such as the float's duty cycles, speed, and torques. Use information to select and buy induction motors and inverter materials.

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PHASE 2: Develop speed based motor controllers and a thermal cooling system for the motor. The goal is to get full speed control of the motors and tires. Batteries are not yet necessary.

⇓

PHASE 3: The final phase is expected to complete the electric rose float and select the appropriate batteries. The final product should be ready to integrate with the float. Complete details are not yet known.

Our team, SLO Drive Systems, is comprised of the following senior mechanical engineering students: Jennifer Slone , Dionysios Pettas, Timothy Baldwin, and Jason Sherrett. We are beginning this project in phase two, continuing from a previous senior project group. The project sponsor is BAE Systems, a global defense and aerospace company. The project's main point of contact at BAE Systems is Charles Combs, a Mechanical Engineer and Cal Poly graduate.

II. BACKGROUND

The Cal Poly Rose Float is one of the few self-built floats that attend the Tournament of Roses. The frame, drivetrain, mechatronic components, and all other systems are designed and built by student teams from Cal Poly San Luis Obispo and Pomona. However, there are very strict design requirements that all floats must meet, whether professionally built or student built. Therefore, the drivetrain and frame (Cal Poly SLO's portion of the float) must be designed and built on par with professional building teams.

Currently, the float is powered by a pair of V-8 internal combustion engines (ICEs) running on propane. One of these engines is used to power hydraulic pumps and motors, which in turn are connected to the wheels of the float. This setup allows the engine to be mounted in various locations on the frame (depending on that particular float design), with the only requirement being the length of the hydraulic lines. However, this compartment system has never been used to its full extent, and the engine has been mounted in the same location since the first float entry. Additionally, there are draw backs to the use of internal combustion engines for propulsion. The first (and most important) of these drawbacks is the heat dissipated by the engine within the confines of the float skeleton. There are typically three to four student operators within the float, so it is necessary to provide cooling air to the chambers where these operators are positioned. This adds complexity to the float design and often interferes with the intended exterior design of the float.

Additional disadvantages to the ICE's used on the float include noise and exhaust gases. The noise is not only a problem for the operators within the float, but can also detract from the overall appeal of the float from the perspective of the Rose Parade attendees. The exhaust gases are also an inconvenience from the standpoint of the float designers and operators. A system of some sort has to be installed that will provide fresh air to the operator chambers, as well as route the exhaust gases away from the chamber and out the back of the float. These factors increase complexity of the float design, resulting in higher curb weight and cost.

Due to the shortcomings of an ICE, an electric drivetrain was proposed for the future Cal Poly Rose Float. This new system would power the float through the use of dual AC induction motors, controlled through the use of a student designed computer interface. This new drivetrain would eliminate many of the drawbacks seen with the big-block engines that previously powered the float. First of all, the heat produced by the motors will be negligible when compared the combustion engines. The motors will only need convective air cooling, eliminating the need for a complex cooling system. Furthermore, exhaust fumes will no longer be a design factor in the float exo-skeleton and operator chambers, further simplifying the overall design. On a similar note, the new drivetrain will be significantly more "green" than the old design, which could result in higher scores from judges and popularity with the general public attending the Float parade.

The project is a multi-part series, the first part of which has already been completed by a 2009 mechanical engineering senior project group. The main goals of the first phase were to size and purchase a motor, assemble physical components, and design a float subframe for mounting the electric drivetrain. The tasks competed by that project group include:

- Appropriate motor sizing specification. The team identified the necessary duty time of the motors based on the parade route length and float speed during that time. The team ensured that the motors would meet all regulations and requirements as set forth by the Rose Float Parade Committee. Required torque, power, and battery specifications based on float weight, drag, required speed, and other parameters were made by this project team as well. One motor has been purchased from Marathon Electric.
- Various inverter components have been purchased and some assembly has taken place. This includes gate drive cards and IGBT's.
- Final drive units have been specified and purchased.
- Electric drivetrain subframe has been designed and fabricated. Allows the temporary mounting of electric drive system on Cal Poly Rose Float. One motor mounted on subframe.
- Various parts for DC power supply specified and purchased.

A variety of documentation from the previous project group has been forwarded on to our team. This documentation includes:

- Previous senior project report written by Nicholas Hellewell, Westen Cooke, Grant Sperry, and Chris Mundy.
- Detailed calculation in Excel spreadsheets. Include calculations and analysis for induction motors, required battery power, rolling/air resistance, etc.
- Preliminary research on hardware (motors, microcontrollers, etc.) and programming requirements to control the hardware.
- User manuals and data sheets for all hardware previously purchased.
- Technical documents and articles used by previous project group in their design process.

III. OBJECTIVES

This project is the second in a series of projects to electrically power the Cal Poly Rose Float. In essence, the main objective of this particular phase is to take over where the first phase left off and continue with their system until we reach a point where the induction motors are spinning under digital control from a physical analog input. The minimum test conditions for this milestone will be a no-load scenario, per the sponsor's directions. If time allows, a closed loop control system will be implemented in order to force a first order system response. The higher order system will be tuned until it has a first order response with the smallest time constant achievable. Most of the mechanical design has been specified by the previous projects. This portion of the project involves preliminary mechatronics control. We will develop a system that responds to human input, and can be refined as further projects test the apparatus for actual application. Safety, as always, is a major concern. For that reason, our programming will incorporate an emergency stop of all current into the inverters, and thus, the motor as well. Since this is a continuing project for a continuing program, smooth integration with the existing parts and methods is a necessity. A summary of the technical specifications, their risk of not being met, and the methods for determining compliance can be found below in Table 1. The lone specification with high risk (Motor Spinning Under Analog Control) is the ultimate deliverable. This is a high risk specification because every other programming condition must be met in order to permit its acceptability. The method of determining these technical specifications was determined with the use of a quality function deployment (QFD) matrix. A discussion of the QFD method and its application to this project can be found in Appendix A.

Table 1. Technical Specifications and Risk Assessment

Spec #	Parameter	Target	Tolerance	Risk	Compliance
1	Emergency Stop Time	0.1 sec	Minimum	Low	Test
2	No-Load System Time Constant	3 sec	Minimum	Med	Test/Analyze
3	PWM Frequency	10 kHz	Maximum	Med	Analyze
4	Motor Spinning Under Analog Control	True	-	High	Inspect
5	Mechanically Compatible with existing Frames	True	-	Low	Inspect/ Analyze
6	Identical Electric Motor	True	-	Low	Inspect
7	Micro-controlled	True	-	Low	Inspect
8	Only Starts if I/P is Zero	True	-	Low	Analyze/Test

IV. METHOD OF APPROACH

This goal can be accomplished using one of two methods: (1) Build a motor controller using various electronic components and writing a custom microcontroller program, or (2) Purchase a commercially available variable frequency drive (VFD) motor controller. While either of these approaches will result in control of the motors, the second approach is far more practical for our team (given our purely mechanical backgrounds). Further advantages and disadvantages of these two methods are discussed in further detail below:

(1) Build a motor controller

The first step in this approach will be to create simulations in Atmel AVR Studio. Initially, this will allow us to learn the programming language and fine tune our logic theory. We will complete simple tasks in the program at first, such as making an LED blink or having text appear when a certain user input is applied. Next, we will begin to simulate the pulse width modulation (TWM) program that we will write for the motor controller. This will allow us to prove whether our program functions in theory before it is actually tested with the hardware. During this time, we will also assemble the appropriate gate cards known as insulated gate bipolar transistors (IGBTs), and other electronics that combine to make up the motor controller hardware.

Next, a DC power supply will be used to provide power to the motors in place of batteries (which will ultimately be used on the float). Testing will begin with basic functions, including validation of the Emergency Stop and Speed Limit functions. Once these functions have been verified, testing will move on to more advanced procedures, including load/speed tests and analog control integration. From here, various conditions and scenarios will be simulated and tested to be sure that the system will function appropriately on the Rose Float.

(2) Purchase a commercially available VFD Motor Controller.

The first option basically requires the creation of our own microcontroller, specific to our needs. The alternative is to purchase a controller and integrate it with our application. Constructing an electric powered vehicle is not a new endeavor. Hence, there are controllers available in the market which can be used to manage the power of our motors. Within this alternative, there exist two different technologies: V/F (variable frequency or “volts per hertz”) control, and Flux Vector control. In order to evaluate our options, we created a comparison table, Table 2, to see how each system would fulfill our needs and expectations.

Table 2: Decision Matrix

Item / Desirability		Program own Microcontroller	Variable Frequency Controller	Flux Vector Control
Control	Proper operation of motors	Leaves method of operation up to programmer, can work with constant torque or constant speed	Will operate much like the throttle on a car, constant torque	Capable of automatically adjusting input for changes in load on motor
Simplicity	Easy to implement and use	Very complex and requires much time and significant knowledge of C programming	Comes with program and is the simplest solution	Slightly higher complexity than V/F drive, newer technology
Cost	Cheaper system to stay within budget	~$1000	~$3000	Over $5000
Programmable	Allows future modification or corrections	Completely customizable by programmer	Some products provide PC based software to customize controller	Some products provide PC based software to customize controller
Closed loop	Uses feedback from motor to control speed	Flexible and allows open loop or closed loop program	User must provide adjustments of input to account for change in load on motor	Makes use of motor encoder to receive feedback and determine shaft position
Integration	Easy to integrate with existing rose float	Requires complete programming but can be customized for our application	Easiest to integrate with existing system	More difficult to integrate, requires setting up with encoder
Stand-alone	System is all one unit	Will be packaged as a stand-alone	Can be a stand-alone or a bus system	Can be a stand-alone or a bus system
Availability	Easy to find and acquire	Chipset and development board are easy to find through Atmel	Older technology and more readily available	Newer technology and generally less abundant

Purchasing a VFD, though its marginal cost is higher than the original intent of the project, is our best option. This project was given to us behind schedule and the time made up by purchasing a commercially produced unit will be well worth the extra money. The commercial VFD will also be more reliable because it will be designed and programmed by professionals with electrical and programming experience, drastically reducing safety concerns. A VFD is also a high-ticket item, so even though we have little familiarity with it, the suppliers are willing to invest extra support from application engineers to make the sale, thus ensuring that we purchase a drive that meets our needs. Also, because we are talking directly with the suppliers, we are much more likely to get a discount or strike a bargain with a company. Possible routes include discounted hardware for sponsorship mention or negotiating on a refurbished drive.

While assembling the entire system from scratch would be beneficial to our group members in the long run, because of the knowledge we would acquire, using a VFD is almost more useful because it allows us to learn more about the process of collaborating with suppliers, setting up third-party equipment, and systems testing. In addition, if a factory needed to run an asynchronous AC motor, the engineers there would purchase a VFD. So, not only are we learning the art of collaboration, but we are learning about a specific process that may more useful in our future work than the programming we would have used otherwise.

Once the decision to go with a VFD (variable-frequency drive) has been made, there remains one more question: Which VFD is appropriate for our given application? This is by no means a simple question and will require a close inspection of our choices. There are many VFD manufacturers around the world, all with a wide variety of drives for every application imaginable. A majority of these VFDs are used in assembly lines or automated factories. However, due to the fact that our application requires a higher degree of control than that of a factory motor, many of the basic VFD models do not comply with our desired performance specifications. Therefore, there are several specific functions and components that our team will be looking for in order to meet our needs.

V/F (volts per hertz) is considered the “simple” option out of the two methods of control. V/F works by sending a command from the user to the microcontroller, which in turn sends the desired current to the motors. This type of control is called “open loop”, meaning that there is no feedback from the motor to tell the microcontroller how to adjust its signal. The scale of the V/F output is always identical, regardless of the applied to the motors. For example, if the float travels at 5mph on flat ground and then encounters a steep grade, the motors will not adjust to the increased load and will effectively slow down. This type of performance can be compared to that of an internal combustion engine. If when driving your vehicle around town, you desire to go faster, you simple push the gas pedal down further. However, for electric motors, just simply pushing the “gas pedal” further (increasing the current draw) is an inefficient way of controlling the motor speed.

On the other hand, vector control is a “closed loop” system. This means that an encoder on the motor sends position and speed to the microcontroller so that it can adjust the PWM signal appropriately. This allows the float operators to maintain a constant speed and/or torque during the parade route regardless of inclines, head winds, etc. The vector control option was selected by the previous senior project team, however after extensive research communicating with the variable frequency drive suppliers in this phase, the V/F method was considered a better option for this project.

Next, the power rating for the controller(s) must be decided on. There are two directions we can go with the hardware selection at this point:

- Two single-output VFDs rated around 40hp each
- One dual-output VFD rated around 75-100hp total

This decision relies heavily on the cost of the actual units. If a dual-output VFD has a price tag equal to more than half of our budget, we might not be able to purchase a second motor. Or if we deemed it necessary to purchase a second motor at this time, we could go with a single output VFD and simply test each motor individually. Ideally, our team would like to purchase a dual-output VFD, which makes more sense in the long run as far as cost and practicality.

V. MANAGEMENT PLAN

Mechanical engineering senior project is divided among three quarters spanning around a year. With the expanse of time given, it is easy to lose track of the end goal. It is therefore necessary to implement a management plan so deadlines are met and the project is completed on time. Early on in the project, the foundations were laid for SLO Drive System's management plan.

A Gantt chart was formed in order to illustrate the projects schedule; it can be viewed in Appendix B. The Gantt chart is basically a bar graph highlighting the start and finish dates of major goals in the project, and it visually shows the progression of the project. This chart will be a useful tool for our team to stay on schedule and be aware of important deadlines.

We as team members also assigned roles amongst ourselves in order to maximize team efficiency. Timothy Baldwin has assumed the coordinator position by leading discussions among the group and helping the flow of the team's progress. Dionysios Pettas has performed much of the background research for the team and has been the main contact for multiple suppliers. Jason Sherrett and Jennifer Slone have been the team's two points of contact between BAE systems and Cal Poly Rose Float. With this management plan we expect that we will be able to meet our deadlines and have the final project ready by December 2010.

(1) Management Plan Update (End of Winter Quarter)

During the first quarter, a shift in the project was made. Originally our team's goal was to learn the encoding necessary to program a microcontroller to control motor spin. However, it was determined that using a VFD would be a better solution to the problem due to the team's minimal experience with programming and mechatronics. This fundamentally changed the management plan of the project. The Gantt chart was rewritten, highlighting the new goals of the project. The focus of Winter quarter was to finalize an appropriate VFD for the already purchased motors. The goal at the end of winter quarter was to purchase a VFD and motor. For Spring quarter, the focus will be on installing the VFD and motor and getting the system operational. For the final quarter (Fall) the focus will be on final testing of the motor VFD system. This information can be found on the Gantt Chart in Appendix B.

(2) Management Plan Update (End of Spring Quarter)

Spring quarter was spent verifying that the selected VFD would work and figuring out how the VFD would be tested. By the end of the quarter, the final selection was made, and the parts were purchased and received. A new Gantt chart was created for the final months of the project. This can be found it Appendix F.

VI. SAFETY PLAN

Safety is one of the most important criteria for designing and building the electric rose float. Our team had to consider both the safety of the rose float operators, parade spectators, and the safety of our team members during the construction of the new float. It is important to incorporate these safety features in the design phase in order to ensure safe operation during testing and prevent future accidents.

Disregarding safety measures could potentially be hazardous to the students operating the float and the crowds of people during the parade. One of the safety measures we have decided on is the incorporation of an emergency-stop (E-stop) to the system. The E-stop will disconnect the battery if there is a problem, preventing accidents from escalating. It is also important to place the motors and batteries where they will be safe for the operators of the float.

While our team was working on the float we dealt with hazardous voltages. For this reason, we obtained the proper instructions for dealing with large voltages and had supervision during use. The E-stop was incorporated early to allow safe testing for the team. It was also important to begin with low current/speeds at first, and then gradually increasing the operating conditions.

Another safety factor considered was the hazards created from rotating parts. When the motor was tested, it was given adequate space from the team members since was spinning at high speeds. Hair, jewelry and loose clothes were all at risk during testing, and were properly secured before operating.

The motor manual lists some other safety measures that must be taken during assembly and operation. The manual should be referenced before any operation. The safety measures are summarized in the table below.

Table 3: Safety Summary

Safety Issue	Prevention
Electrical Shock Hazard	Proper instillation and maintenance.
Electrical Grounding Hazard	Ground motor according to NEC Article 430 instructions.
Rotating Hazard	Remove loose clothing and tie back hair. Remove any loose parts.
Location Hazard	Test and run motor in space with adequate room and ventilation. Keep the motor away from hazardous materials and chemicals.

VII. MAINTENANCE AND REPAIR

In order to keep the float motor and VFD systems running at peak performance and minimize repair costs, the motor and VFD maintenance procedures were reviewed and summarized. The maintenance procedures were obtained from the motor and VFD manuals and should be reviewed before operation of the system. This section should not be substituted for reading the motor and VFD manuals, but rather be used as reference after they have been reviewed, and for estimation of maintenance necessary. The safety section should regularly be reviewed as well before maintenance is preformed.

The most important action for peak performance of the system is proper setup. Setup details can be found in the previous section. However, after proper setup, the following actions should be taken.

1. Bearing Lubrication
2. Low Operating Speeds
3. Inspection
4. Storage

(1) Bearing Lubrication

Bearing lubrication should regularly be performed after one year of use. The lubrication table can be found in the manual. The tables use the following equation to calculate lubrication intervals:

Lubrication Interval = [(Table 4-1) hrs] x [Interval Multiplier (Table 4-2)] x [Construction Multiplier (Table 4-3)].

The motor selected has a frame size of 324 T. Using this information, and Table 4-1 from the manual and the parade rpm of 1727 rpm, the table suggests lubrication every 9,000 hrs. The interval and construction multipliers are both assumed to be 1.0 because most of the year the float will not be operated. Since the float is run at low speeds infrequently throughout the year lubrication is only recommended once a year. From the manual, a volume of 33.0 mL lubrication is needed. To add the grease the correct lubricant must be selected and must be free of any contaminants. The grease inlet must be cleaned and blockages removed. If there are blockages see manual for removal information.

Key Information: Lubricate 1 time/year with 33.0mL lubricant

(2) Operating Speeds

To prevent overspeed, a max rpm of 3600 is suggested for the motor. However, the rubber tires on the float limit the speed of the float and it is predicted that the operating speed of the float will never exceed the max recommended by the manufacturer.

(3) Inspection

The motor should be inspected every 500 hrs of operation or every 3 months. The ventilation, insulation and electrical connections should be inspected. The motor ventilation openings should be free of dirt and grease. The winding insulation can be checked using a "Megger" reading. The electrical connections should be check to see if they are still tight.

Key Information: Inspect VENTILATION, INSULATION and CONNECTIONS every 500 hrs or 3 months.

(4) Location

The float will spend most of its time not in operation. The following steps should be taken to ensure safe storage. The motor should be safe from direct sunlight, corrosives harmful gases or liquids, vibration, dust and rain.

Key Information: Store the system in a well ventilated indoor location or covered when not in use.

If the float requires repair even after proper maintenance the manual contains a section on common repair troubleshooting. If the fix is more complicated than the ones in the guide, the repair should be performed by a professional.

IIX. DETAILED DESIGN

(1) Motor Analysis

In order to appropriately size the motors that will be used to power the rose float, an excel spread sheet was set up to calculate the required power over a variety of conditions. Three different test scenarios were initially modeled: Top Speed, Hill Climb, and Parade Route. For each of these scenarios, it was assumed that the overall efficiency of the rose float (rolling resistance, drag force, etc.) and electronics would remain constant and all ambient conditions (air density, temperature, etc.) would remain constant as well. Additionally, all specifications and parameters pertaining to the float would remain constant (weight, tire diameter, frontal area, etc.).

For the Top Speed simulation, it was assumed that the rose float would be traveling at a speed of 10mph. This speed was chosen based on recommendations from the rose float coordinator, Josh D'Acquisto, from his past experiences with transporting the float to the rose parade. For the Hill Climb simulation, it was assumed that the float would travel up a 6% grade at a speed of approximately 3.5mph. Lastly, for the Parade simulation, it was assumed that the float would travel at an average speed of 6.5mph and up a grade of 2%. As a result, a maximum required power output from each motor was calculated to be 23 kW (Top Speed simulation).

The next step was to select an AC motor that would provide the required power. The Charged Floats senior project team decided to go with a 30 kW (40 hp) Marathon BlueMax Y513-A775 AC motor. When compared to other similar motors, the cost of the Marathon motor was approximately $2,000 less and performed equivalently. To ensure that the BlueMax Y513-A775 would be powerful enough to move the float through all of the conditions simulated earlier, the maximum required torque for each condition was calculated and plotted against the maximum torque possible.

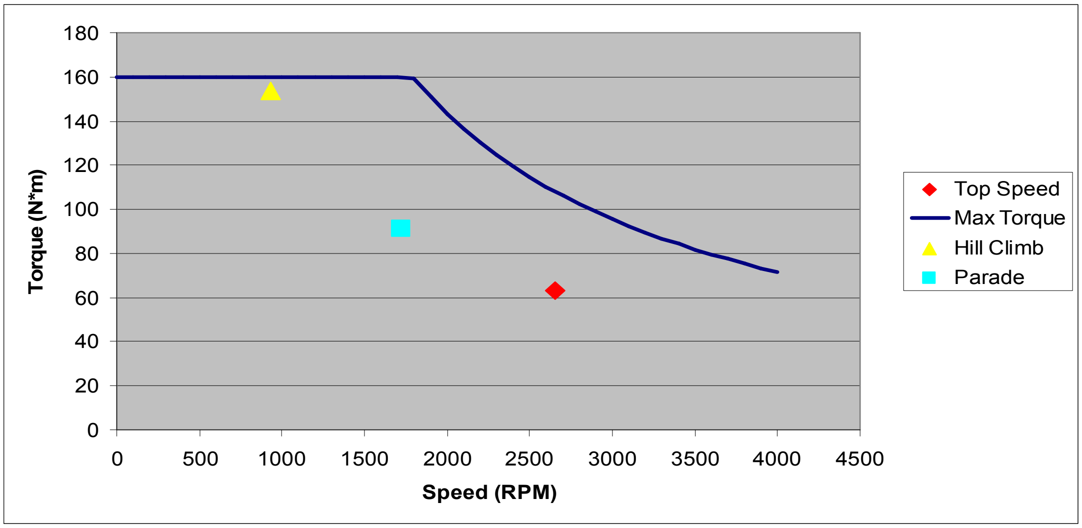


Figure 1: Blue Max Y513-A775 AC Motor Data
The required torques for all three simulations are below the maximum torque line

As you can see, the required torques for all three simulations are below the maximum torque line of the motor. This means that the motor has been adequately sized. One Marathon motor has already been purchased and mounted to the rose float extension frame. The next step will be to purchase a second BlueMax motor and fabricate another identical mounting plate.

(2) Motor Mounting

As a result of the first senior project team, one Marathon motor has been mounted to the rose float extension frame. The motor mount is fabricated from a single ½" steel plate approximately 18" by 30". This plate was then welded to the extension frame in the appropriate location. Next, the motor was suspended just above the mount (through the use of an engine hoist) so that the motor mount holes could be marked and drilled. Lastly, the motor was bolted to the mounting plate and shimmed to the correct angle (dependant on final drive alignment). For the second phase of the project, it will be necessary to fabricate and install a similar motor mount design for the second Marathon motor. However, we are anticipating the need for a revised shimming system. Currently, the shims being used are made from low-strength plastic, whose integrity may be compromised under full motor torque. We are looking into the possibility of machining custom shims or ordering off-the-shelf shims.

Additionally, flange adapters will need to be designed that will connect the C-flange on the motor to the SAE-B flange of the final drive unit. This flange will ensure proper alignment between the motor output shaft and the final drive spline adapter. At low speed and torque, which our testing will begin with, the flange adapters are not necessary. However, as the load on the motor increases and there is a greater torque applied to the mount, the output shaft of the motor and the spline adapter of the final drive unit can tend to come out of alignment. This can result in a failed bearing, decreased efficiency, and even a broken motor shaft. Therefore, it is absolutely necessary that a flange adapter be implemented before the motors are run under load.

(3) Variable Frequency Drive (VFD) Selection

As mentioned previously, we debated about purchasing a single dual-output VFD or two separate single-output VFDs. The cost for both setups would be approximately equal and both would allow for complete motor control. However, it was deduced that having one drive for each motor could allow for the possibility of controlling the speed of each drive wheel independently. This scenario could be useful if the float had to maneuver in tight corners. Furthermore, space is not in short supply on the rose float frame, so the mounting of two separate units would not be a major hindrance to the operation of the float. Therefore, the decision was made to purchase two separate single-output VFDs. Due to budget restraints, unfortunately, we would only be able to conduct adequate testing to verify the operation of the system. The last step will be to simply purchase a second motor and VFD, and install them similarly to the pair that we tested.

Figure 2: Fuji Frenic Series VFD

After thorough research, vendor communication and product comparison, our team has chosen to go with a Fuji Frenic Series Drive. Specifically, we purchased the Fuji FRN040G11S-2UX (pictured on left in Figure 2), a 40 hp drive in a Nema1 enclosure with a nominal AC input of 230V (and optional DC input). This drive can power up to a 30 kW (40 hp) AC induction motor, and is rated for a current of approximately 120 amps. Additionally, it was determined, through calculations of simulated conditions, that the motor will only need to supply approximately 18 kW (or 24 hp) during the parade route. Therefore, an additional factor of safety in the VFD selection was not necessary. The new schematic and bill of materials for this design can be found in Appendix C.

(4) Variable Frequency Drive (VFD) Mounting

Hardware mounts will need to be designed and attached to the float extension. These mounts will be made out of 1.25” x 0.065 wall square tubing and will be welded to the frame rails of the extension piece. We will provide dimensioned drawings of the VFDs so that mounting can be designed and installed appropriately.

(5) Cost Analysis

Particular attention was paid to ensuring that we could achieve our objective within the allotted budget of $10,000. This became increasingly challenging with the decision to purchase a commercially available VFD to control our motors. A necessary component to be purchased is an identical Marathon motor which costs $4,200 from Automation Direct as the supplier. This price includes an encoder and phase cables used with the motor. The purchasing of the Marathon motor will occur in the final phase of the project. A Fugi Frenic drive was purchased from Direct Drives, after a significant amount of research and negotiating, the cost for this item was $ 4,283. The purchase of a power supply was also necessary in order to test the VFD and motor. A power supply was purchased from Ametek Pogrammable-Power Inc. and had a cost of $2,990. This left us with a balance of roughly $2727, which made the purchase of a second VFD impossible in this phase of the project. Instead, we decided to leave the residual funds for any other unexpected materials and expenses (such as cables, connections, etc.). We also took into consideration the third phase of the project. A sufficient power source is still needed to complete the project and with just one phase to follow us (with an expected budget of $10,000) we needed to be sure that the float can be completed. With the voltage required for the motors, it was determined that the batteries needed would come out to nearly $6,000. The power supply purchased in this phase will be unnecessary to the final project and can be sold in order to gain additional funding. Therefore, we believe that there will be sufficient funding to allow the purchase of the second VFD and motor.

IX. PRODUCT REALIZATION

(1) Manufacturing Process

After purchasing the necessary components, the variable frequency drive and induction motor were connected and motor control was gained. The following is a list of components used in the assembly:

- *Variable Frequency Drive (VFD)*
- *Power Supply*
- *12 Volt Battery*

- *Potentiometer*
- *Ground Wire*
- *2 DC Powered Fans*
- *Induction Motor*

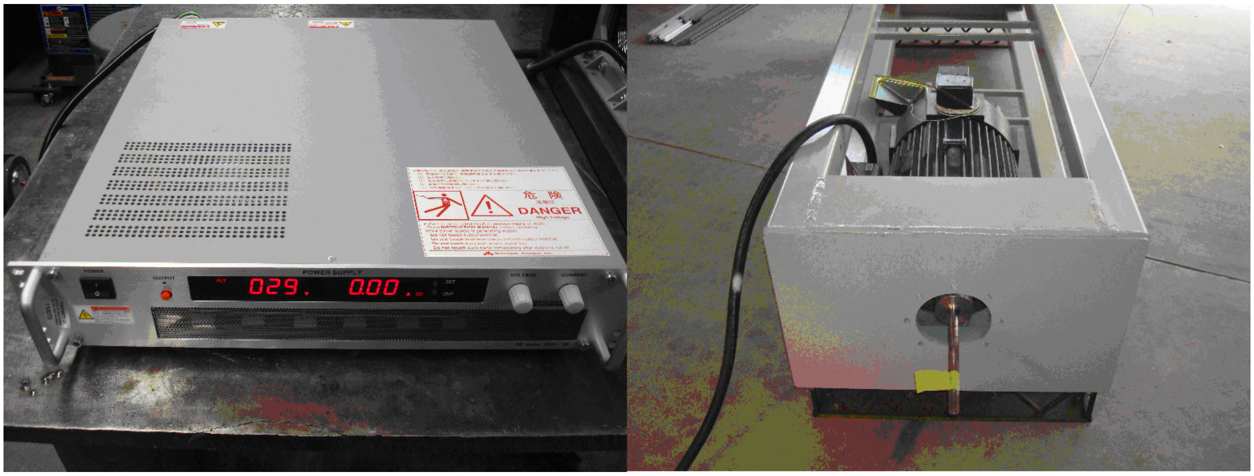


Figure 3: Power Supply and Motor

Figure 4: Connected System
Photograph of connected power supply and VFD. Induction motor is also connected but not pictured.

The fans used for cooling the VFD were AC powered and had to be swapped with 2 DC powered fans. Minor adjustments to the fans were made to allow it to be installed, and the 12 volt battery was used to power the new fans.

The process of assembly began with the connection of the potentiometer into terminals 11, 12, and 13 of the VFD. Next the motor was connected to the VFD at terminals U, V, and W. A ground was connected from the VFD terminal labeled ground to the table/ frame. The power supply was connected at P+ and N-. Finally the DC powered fans were connected to the 12 Volt Battery.

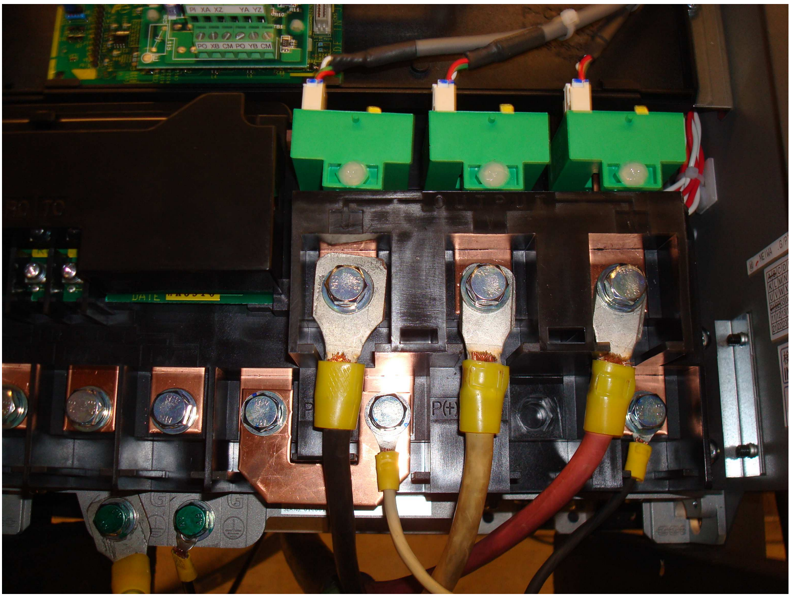


Figure 5: VFD, Power Supply, and Motor Connections
This photo shows the three connections between the motor and the VFD at terminals U, V and W. Also shown is the connection between the power supply and VFD at terminals P+ and N-.

Before the setup was switched on, multiple inspections were performed. All connections were doubled checked, and page 3-1 of the VFD manual was referenced for additional inspections. Finally the cover was placed on top of the VFD for safety.

The power supply was plugged in and turned on. The DC powered fans were turned on as well. For the first test values of 325 Volts 3 and Amps were set, as this was within the range of values suggested by the manual. The output button was selected on the power supply and the VFD responded by activating the keypad. Using the keypad motor response was achieved. Spinning was achieved with the potentiometer after changing the settings using the instructions on page 5-7 of the manual.

(2) Initial Run Notable Occurrences

- The forward setting caused the motor shaft to rotate counter-clockwise, and the reverse setting caused a clockwise rotation.

- After the motor rotated for a period of time with the initial settings, an under voltage light turned on and turned off the spinning.

- The motor was noisy during operation, and lubrication may be necessary.

- After power supply was cut and then returned, the VFD settings were still saved.

- The VFD took around 1 min to turn off after power was cut.

- According to manual, VFD Bus voltage must be allowed to drop to 25 volts after power is cut before it can be handled. It took 3 minutes to discharge the motor to 25 volts.

(3) Differences from Original Plan

The original plan, at the beginning of this project, was to program a microcontroller in order to gain motor control of the rose float. Due to the team's lack of experience with programming and the project time constraints, our team made the decision in the first quarter of senior project to purchase a commercially available variable frequency drive compatible with our motor. This required the additional purchase of power supply for testing purposes.

(4) Recommendations for the Future Manufacturing of this Project

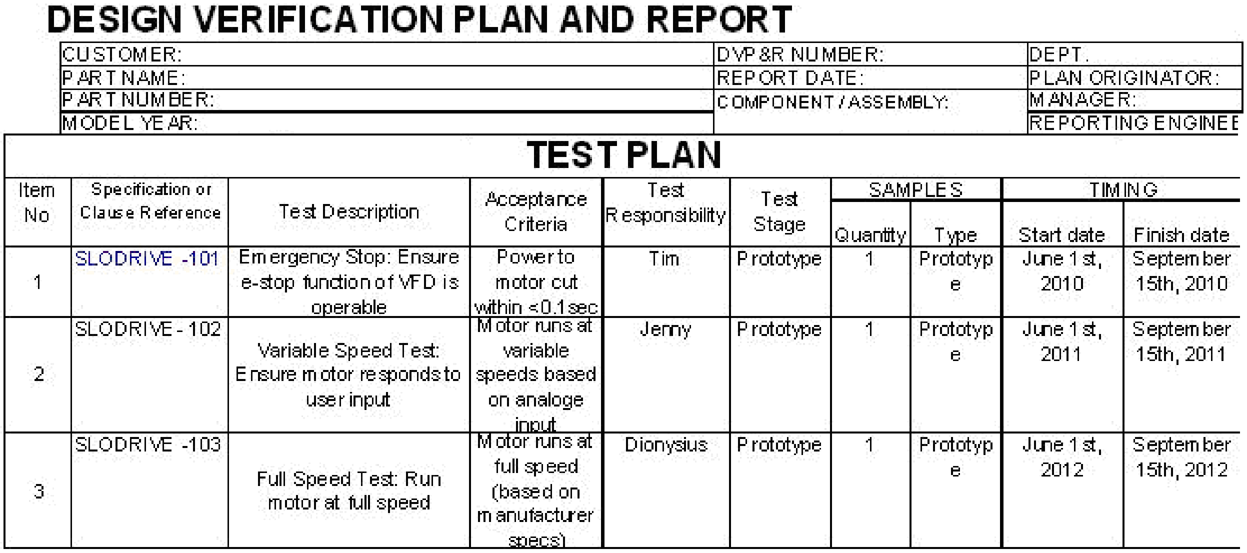
A team of students will resume this project and bring it to completion after we are finished. Our team recommends this project be transferred to electrical engineering students for the final phase. We recommend that the next team purchase another matching variable frequency drive and motor. The setup process for these components can be found in the Manufacturing Process section of this report. After these components are received, the VFD manual should be referenced to determine how to connect the two VFD/motor systems. The new team will need to research and determine the batteries necessary to run the float and purchase those as well. The power supply purchased in our project will be unnecessary with the addition of batteries, so our team recommends that the power supply be sold for additional money for the project. The next team will need to connect the batteries to the VFD/motor systems and mount the VFDs and the second motor.

X. DESIGN VERIFICATION

The testing of the rose float drive system will be an incremental system, one test building upon the previous results. It is extremely important that safety precautions are followed and that tests are completed to their full extent before moving on with the project. Failure to do so could result in hardware failure or serious injury/death to a team member. Therefore, the first test to be carried out was the trials of the emergency features of the system. An “emergency stop” feature is built into the drive that our team purchased, and we tested its use first. For this test, we applied a small voltage (48V) to the motor so that it is spinning slowly. We then activated the emergency stop, and measured the line voltage. It dropped to zero immediately and the motor stopped spinning thereafter.

Further tests include a variable speed test and a full speed test. Each of these tests is explained in further detail in the Design Verification Plan and Report below.

Table 4: Testing Plan for Project (DVPR)



DESIGN VERIFICATION PLAN AND REPORT

CUSTOMER:	DVP&R NUMBER:	DEPT.
PART NAME:	REPORT DATE:	PLAN ORIGINATOR:
PART NUMBER:	COMPONENT / ASSEMBLY:	MANAGER:
MODEL YEAR:		REPORTING ENGINEE

TEST PLAN

Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING	
						Quantity	Type	Start date	Finish date
1	SLODRIVE -101	Emergency Stop: Ensure e-stop function of VFD is operable	Power to motor cut within <0.1sec	Tim	Prototype	1	Prototype	June 1st, 2010	September 15th, 2010
2	SLODRIVE - 102	Variable Speed Test: Ensure motor responds to user input	Motor runs at variable speeds based on analoge input	Jenny	Prototype	1	Prototype	June 1st, 2011	September 15th, 2011
3	SLODRIVE -103	Full Speed Test: Run motor at full speed	Motor runs at full speed (based on manufacturer specs)	Dionysius	Prototype	1	Prototype	June 1st, 2012	September 15th, 2012

(1) Results of Test 1: Emergency Stop

An emergency stop test was performed on October 15th 2010. As the motor was spinning, the emergency stop on the keypad was activated, and the motor responded accordingly.

(2) Results of Test 2: Variable Speed Test

A variable speed test was performed on October 15th 2010. When the potentiometer was increased or decreased the motor responded accordingly.

(3) Results of Test 3: Full Speed Test

On October 15th 2010, the motor was run at the speeds required for float operation. System ran successfully with no complications.

XI. CONCLUSIONS

As mentioned previously, the goal of this project was to gain motor control of the three phase induction motor selected by the previous senior project team. That goal was accomplished through the purchase of a Fugi Frenic variable frequency drive, and a power supply used to the test the motor/VFD setup. The final team to work on the rose float electric vehicle project will need to purchase an additional Marathon motor, and an additional Fugi Frenic VFD, and batteries to power the float. It will be the goal of the final team to assemble and mount these components, and bring the electric float to operation. The contact information for the vendors used in this project can be found in Appendix G of this report. The purchasing plan for the major components of the final phase of this project is summarized below.

Table 5: Summary of Parts to Purchase

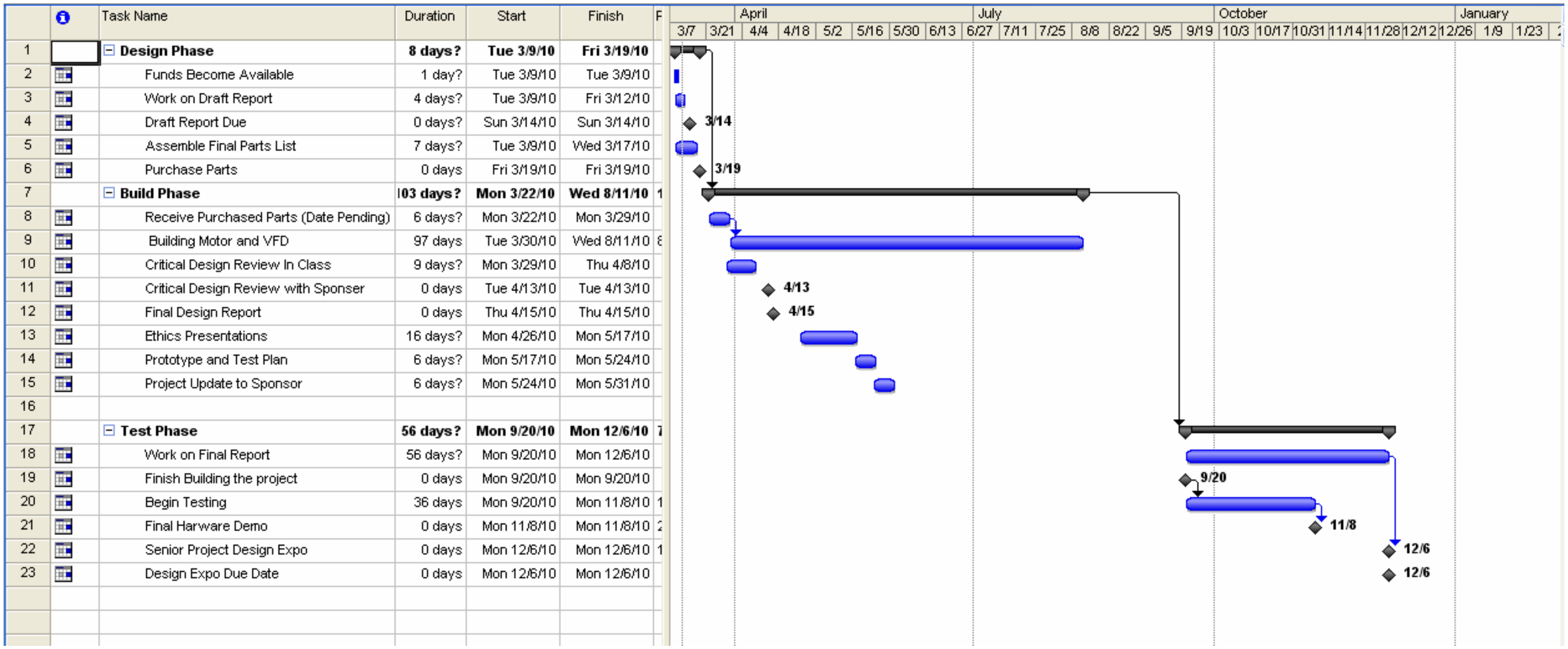
Component	Part/ Vendor	Quantity	Cost
VFD	Fuji FRN040G11S-2UX/ Direct Drives	1	$ 4,283
Induction Motor	Marathon Blue Max Y513-A775/ Automation Direct	1	$ 4,200

APPENDIX A: QUALITY FUNCTION DEPLOYMENT (QFD)

Quality function deployment is a method for taking customer needs in lay-terms and transforming them into engineering specifications. The specifications then can be weighted according to how important they are in relation to the importance of the needs of the customer. This process can be condensed onto a spreadsheet as show in this appendix. The customer's needs are listed and assigned relative importance on an arbitrary scale. Preliminary specifications are then offered and placed along the top. The real power of QFD comes in the correlation between needs and specifications. Needs are matched up to specifications based on how much each specification contributed to meeting each particular need. A weighted average of each specification then produces each specification's relative importance. The results of this process are posted here for reference.

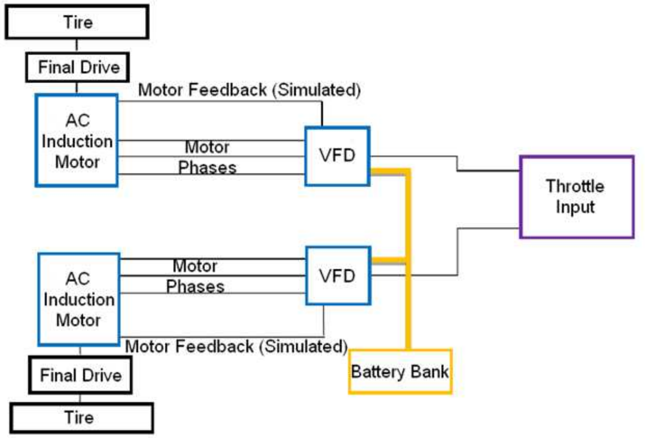
Customer Attributes, Needs, Requirements, or Demanded Quality	Relative Importance or Weight	Emergency Stop Time	First order Response w/ Motor Time Constant <	PWM frequency >	Motor Spinning Under Analog Control	Mechanically Compatible	Identical Electric Motor	Microcontrolled	Only Starts is I/P Is Zero
Sync with existing modular float frame	10					9			
Sync with existing senior project parts	9			3	9				
Easy to drive	7		9					3	
Safe	10	9					1		9
Reliable	10			3				3	
Cool Running	6					3	9		
"Green"	6						9		
Direction of Improvement		D	D	U	N	N	N	N	N
Measurement Units		Seconds	Seconds	kHz	Logic	Logic	Logic	Logic	Logic
Our Value		0.1	3	10	TRUE	TRUE	TRUE	TRUE	TRUE
Weighted Importance		90	63	57	81	108	118	57	90
% Importance		13.6	9.5	8.6	12.2	16.3	17.8	8.6	13.6

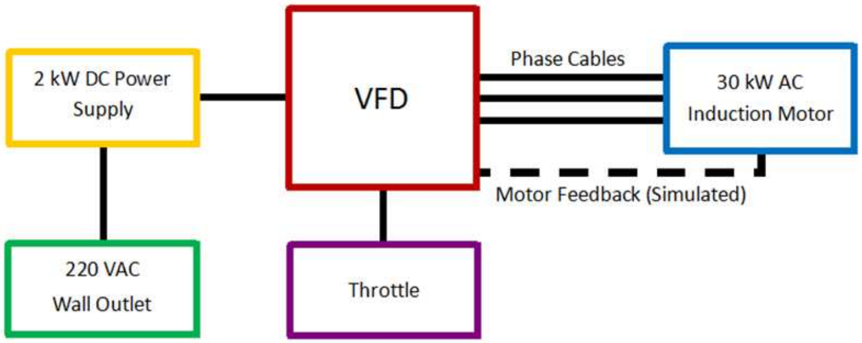
APPENDIX B: GANTT CHART (INITIAL)



	Task Name	Duration	Start	Finish
1	**Design Phase**	**8 days?**	**Tue 3/9/10**	**Fri 3/19/10**
2	Funds Become Available	1 day?	Tue 3/9/10	Tue 3/9/10
3	Work on Draft Report	4 days?	Tue 3/9/10	Fri 3/12/10
4	Draft Report Due	0 days?	Sun 3/14/10	Sun 3/14/10
5	Assemble Final Parts List	7 days?	Tue 3/9/10	Wed 3/17/10
6	Purchase Parts	0 days	Fri 3/19/10	Fri 3/19/10
7	**Build Phase**	**103 days?**	**Mon 3/22/10**	**Wed 8/11/10**
8	Receive Purchased Parts (Date Pending)	6 days?	Mon 3/22/10	Mon 3/29/10
9	Building Motor and VFD	97 days	Tue 3/30/10	Wed 8/11/10
10	Critical Design Review In Class	9 days?	Mon 3/29/10	Thu 4/8/10
11	Critical Design Review with Sponser	0 days	Tue 4/13/10	Tue 4/13/10
12	Final Design Report	0 days	Thu 4/15/10	Thu 4/15/10
13	Ethics Presentations	16 days?	Mon 4/26/10	Mon 5/17/10
14	Prototype and Test Plan	6 days?	Mon 5/17/10	Mon 5/24/10
15	Project Update to Sponsor	6 days?	Mon 5/24/10	Mon 5/31/10
16				
17	**Test Phase**	**56 days?**	**Mon 9/20/10**	**Mon 12/6/10**
18	Work on Final Report	56 days?	Mon 9/20/10	Mon 12/6/10
19	Finish Building the project	0 days	Mon 9/20/10	Mon 9/20/10
20	Begin Testing	36 days	Mon 9/20/10	Mon 11/8/10
21	Final Harware Demo	0 days	Mon 11/8/10	Mon 11/8/10
22	Senior Project Design Expo	0 days	Mon 12/6/10	Mon 12/6/10
23	Design Expo Due Date	0 days	Mon 12/6/10	Mon 12/6/10

APPENDIX C: SCHEMATICS AND BOM

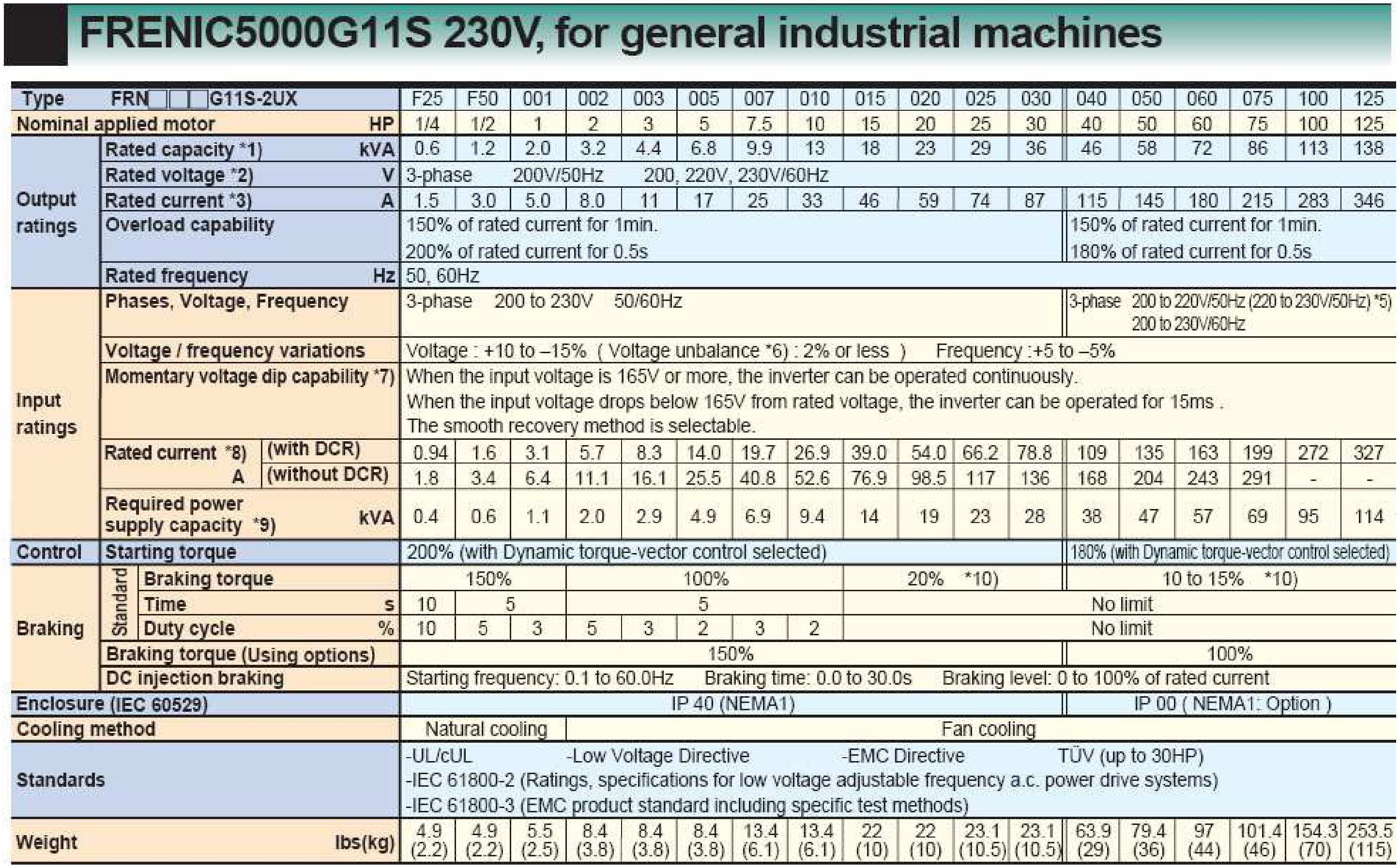




This Bill of Materials contains a list of the major components of this particular phase of the electric rose float project.

Item	Part	Quantity in Design	Quantity to Purchase
Variable Frequency Drive	Fugi Frenic	2	2
Induction Motor	Marathon Blue Max Y513-A775	2	1
Throttle Input	Rheostat	1	1
Input Wire	Thin Insulated Wire	1	1

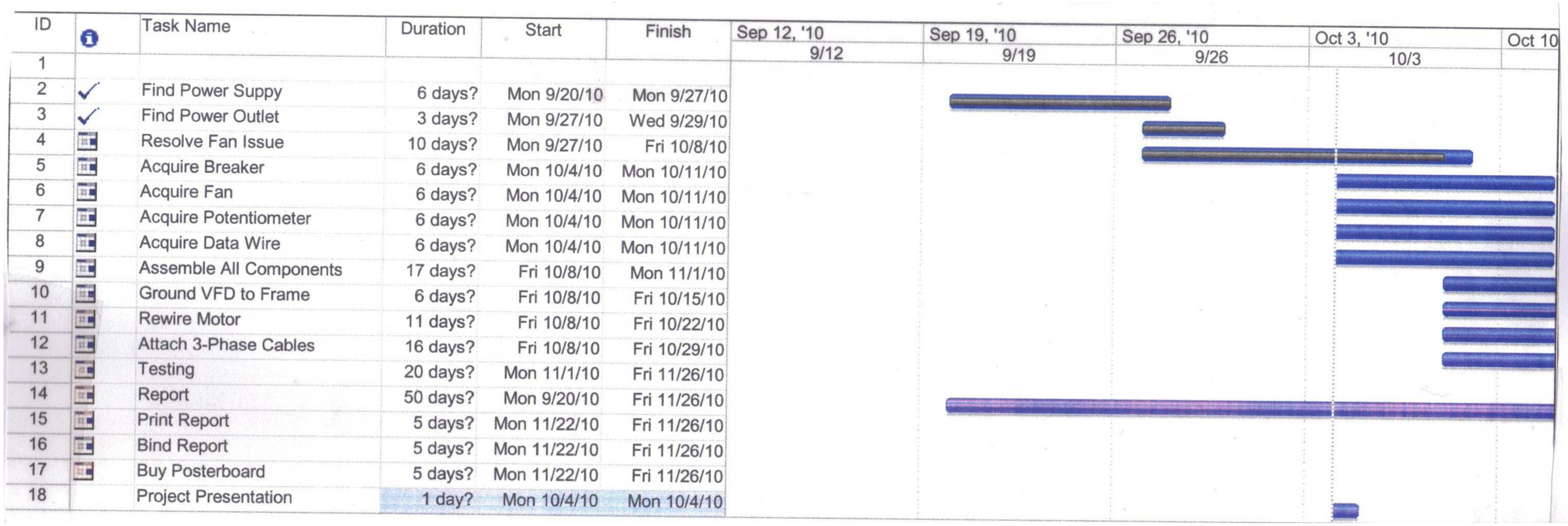
APPENDIX D: VFD DATA SHEETS



FRENIC5000G11S 230V, for general industrial machines

Type	FRN☐☐☐G11S-2UX		F25	F50	001	002	003	005	007	010	015	020	025	030	040	050	060	075	100	125
Nominal applied motor		HP	1/4	1/2	1	2	3	5	7.5	10	15	20	25	30	40	50	60	75	100	125
Output ratings	Rated capacity *1)	kVA	0.6	1.2	2.0	3.2	4.4	6.8	9.9	13	18	23	29	36	46	58	72	86	113	138
	Rated voltage *2)	V	3-phase 200V/50Hz 200, 220V, 230V/60Hz																	
	Rated current *3)	A	1.5	3.0	5.0	8.0	11	17	25	33	46	59	74	87	115	145	180	215	283	346
	Overload capability		150% of rated current for 1min. 200% of rated current for 0.5s												150% of rated current for 1min. 180% of rated current for 0.5s					
	Rated frequency	Hz	50, 60Hz																	
Input ratings	Phases, Voltage, Frequency		3-phase 200 to 230V 50/60Hz												3-phase 200 to 220V/50Hz (220 to 230V/50Hz) *5) 200 to 230V/60Hz					
	Voltage / frequency variations		Voltage : +10 to –15% (Voltage unbalance *6) : 2% or less) Frequency :+5 to –5%																	
	Momentary voltage dip capability *7)		When the input voltage is 165V or more, the inverter can be operated continuously. When the input voltage drops below 165V from rated voltage, the inverter can be operated for 15ms . The smooth recovery method is selectable.																	
	Rated current *8) A	(with DCR)	0.94	1.6	3.1	5.7	8.3	14.0	19.7	26.9	39.0	54.0	66.2	78.8	109	135	163	199	272	327
		(without DCR)	1.8	3.4	6.4	11.1	16.1	25.5	40.8	52.6	76.9	98.5	117	136	168	204	243	291	-	-
	Required power supply capacity *9)	kVA	0.4	0.6	1.1	2.0	2.9	4.9	6.9	9.4	14	19	23	28	38	47	57	69	95	114
Control	Starting torque		200% (with Dynamic torque-vector control selected)												180% (with Dynamic torque-vector control selected)					
Braking	Standard Braking torque		150%			100%					20% *10)				10 to 15% *10)					
	Standard Time	s	10	5		5					No limit									
	Standard Duty cycle	%	10	5	3	5	3	2	3	2	No limit									
	Braking torque (Using options)		150%												100%					
	DC injection braking		Starting frequency: 0.1 to 60.0Hz Braking time: 0.0 to 30.0s Braking level: 0 to 100% of rated current																	
Enclosure (IEC 60529)			IP 40 (NEMA1)												IP 00 (NEMA1: Option)					
Cooling method			Natural cooling			Fan cooling														
Standards			-UL/cUL -Low Voltage Directive -EMC Directive TÜV (up to 30HP) -IEC 61800-2 (Ratings, specifications for low voltage adjustable frequency a.c. power drive systems) -IEC 61800-3 (EMC product standard including specific test methods)																	
Weight		lbs(kg)	4.9 (2.2)	4.9 (2.2)	5.5 (2.5)	8.4 (3.8)	8.4 (3.8)	8.4 (3.8)	13.4 (6.1)	13.4 (6.1)	22 (10)	22 (10)	23.1 (10.5)	23.1 (10.5)	63.9 (29)	79.4 (36)	97 (44)	101.4 (46)	154.3 (70)	253.5 (115)

APPENDIX F: FALL QUARTER GANTT



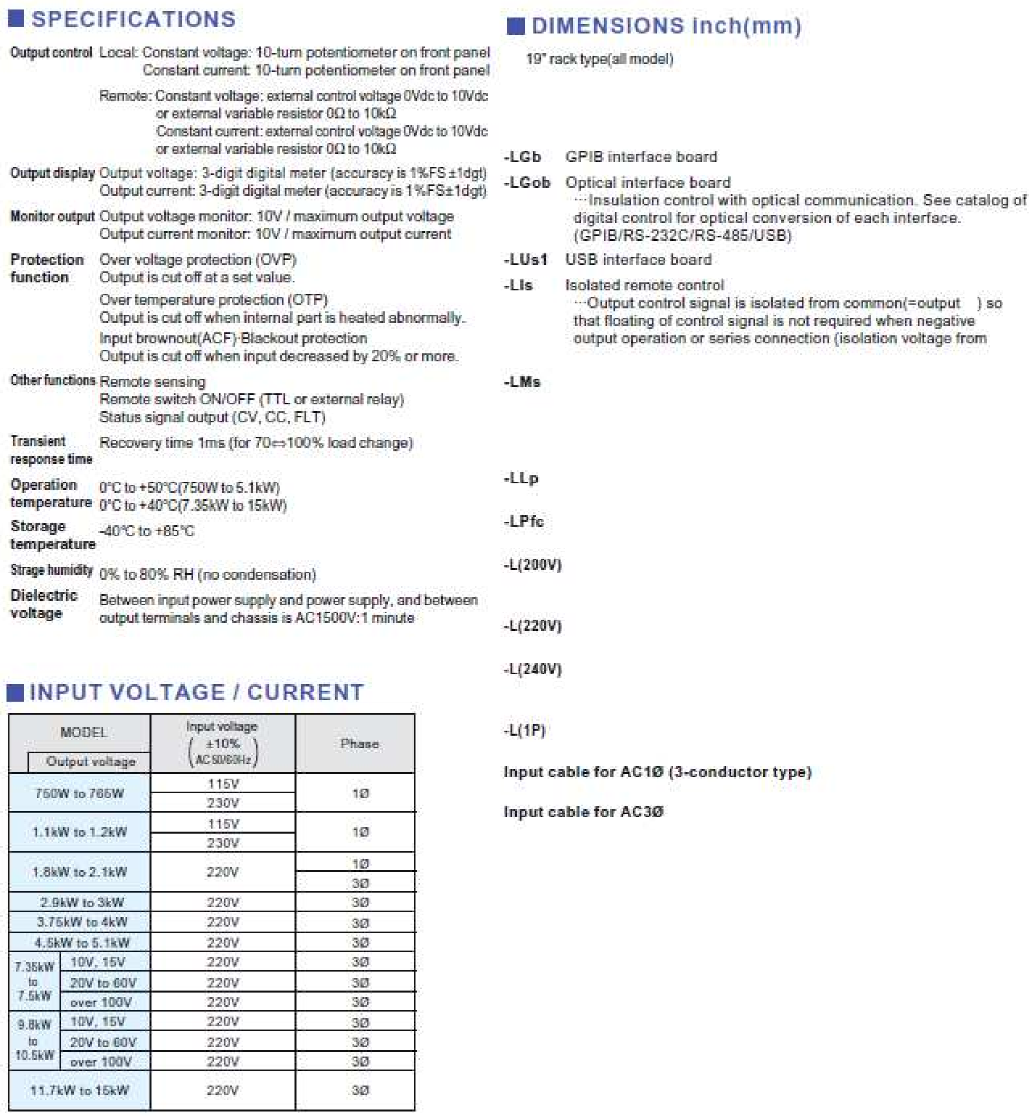
ID	ℹ	Task Name	Duration	Start	Finish
1					
2	✓	Find Power Suppy	6 days?	Mon 9/20/10	Mon 9/27/10
3	✓	Find Power Outlet	3 days?	Mon 9/27/10	Wed 9/29/10
4	▦	Resolve Fan Issue	10 days?	Mon 9/27/10	Fri 10/8/10
5	▦	Acquire Breaker	6 days?	Mon 10/4/10	Mon 10/11/10
6	▦	Acquire Fan	6 days?	Mon 10/4/10	Mon 10/11/10
7	▦	Acquire Potentiometer	6 days?	Mon 10/4/10	Mon 10/11/10
8	▦	Acquire Data Wire	6 days?	Mon 10/4/10	Mon 10/11/10
9	▦	Assemble All Components	17 days?	Fri 10/8/10	Mon 11/1/10
10	▦	Ground VFD to Frame	6 days?	Fri 10/8/10	Fri 10/15/10
11	▦	Rewire Motor	11 days?	Fri 10/8/10	Fri 10/22/10
12	▦	Attach 3-Phase Cables	16 days?	Fri 10/8/10	Fri 10/29/10
13	▦	Testing	20 days?	Mon 11/1/10	Fri 11/26/10
14	▦	Report	50 days?	Mon 9/20/10	Fri 11/26/10
15	▦	Print Report	5 days?	Mon 11/22/10	Fri 11/26/10
16	▦	Bind Report	5 days?	Mon 11/22/10	Fri 11/26/10
17	▦	Buy Posterboard	5 days?	Mon 11/22/10	Fri 11/26/10
18		Project Presentation	1 day?	Mon 10/4/10	Mon 10/4/10

APPENDIX G: LIST OF VENDORS

1. Fugi Frenic Drive: Direct Drives & Controls Inc.
Address: 2485 N. Batavia Street Orange, CA 92685
Phone: 800-428-9347
Main Point of Contact: Chris Miller

2. Power Supply: Matsusada Precision Inc.
Address: 2570 North First Street, Suite 200 San Jose, CA, 95131
Phone: 858-458-0223

APPENDIX H: POWER SUPPLY SPECIFICATIONS



SPECIFICATIONS

Output control Local: Constant voltage: 10-turn potentiometer on front panel
Constant current: 10-turn potentiometer on front panel
Remote: Constant voltage: external control voltage 0Vdc to 10Vdc
or external variable resistor 0Ω to 10kΩ
Constant current: external control voltage 0Vdc to 10Vdc
or external variable resistor 0Ω to 10kΩ

Output display Output voltage: 3-digit digital meter (accuracy is 1%FS ±1dgt)
Output current: 3-digit digital meter (accuracy is 1%FS±1dgt)

Monitor output Output voltage monitor: 10V / maximum output voltage
Output current monitor: 10V / maximum output current

Protection function Over voltage protection (OVP)
Output is cut off at a set value.
Over temperature protection (OTP)
Output is cut off when internal part is heated abnormally.
Input brownout(ACF)·Blackout protection
Output is cut off when input decreased by 20% or more.

Other functions Remote sensing
Remote switch ON/OFF (TTL or external relay)
Status signal output (CV, CC, FLT)

Transient response time Recovery time 1ms (for 70⇔100% load change)

Operation temperature 0°C to +50°C(750W to 5.1kW)
0°C to +40°C(7.35kW to 15kW)

Storage temperature -40°C to +85°C

Strage humidity 0% to 80% RH (no condensation)

Dielectric voltage Between input power supply and power supply, and between output terminals and chassis is AC1500V:1 minute

INPUT VOLTAGE / CURRENT

MODEL	Output voltage	Input voltage (±10% AC 50/60Hz)	Phase
750W to 765W		115V	1Ø
		230V	
1.1kW to 1.2kW		115V	1Ø
		230V	
1.8kW to 2.1kW		220V	1Ø
			3Ø
2.9kW to 3kW		220V	3Ø
3.75kW to 4kW		220V	3Ø
4.5kW to 5.1kW		220V	3Ø
7.35kW to 7.5kW	10V, 15V	220V	3Ø
	20V to 60V	220V	3Ø
	over 100V	220V	3Ø
9.8kW to 10.5kW	10V, 15V	220V	3Ø
	20V to 60V	220V	3Ø
	over 100V	220V	3Ø
11.7kW to 15kW		220V	3Ø

DIMENSIONS inch(mm)

19" rack type(all model)

-LGb GPIB interface board

-LGob Optical interface board
···Insulation control with optical communication. See catalog of digital control for optical conversion of each interface. (GPIB/RS-232C/RS-485/USB)

-LUs1 USB interface board

-LIs Isolated remote control
···Output control signal is isolated from common(=output) so that floating of control signal is not required when negative output operation or series connection (isolation voltage from

-LMs

-LLp

-LPfc

-L(200V)

-L(220V)

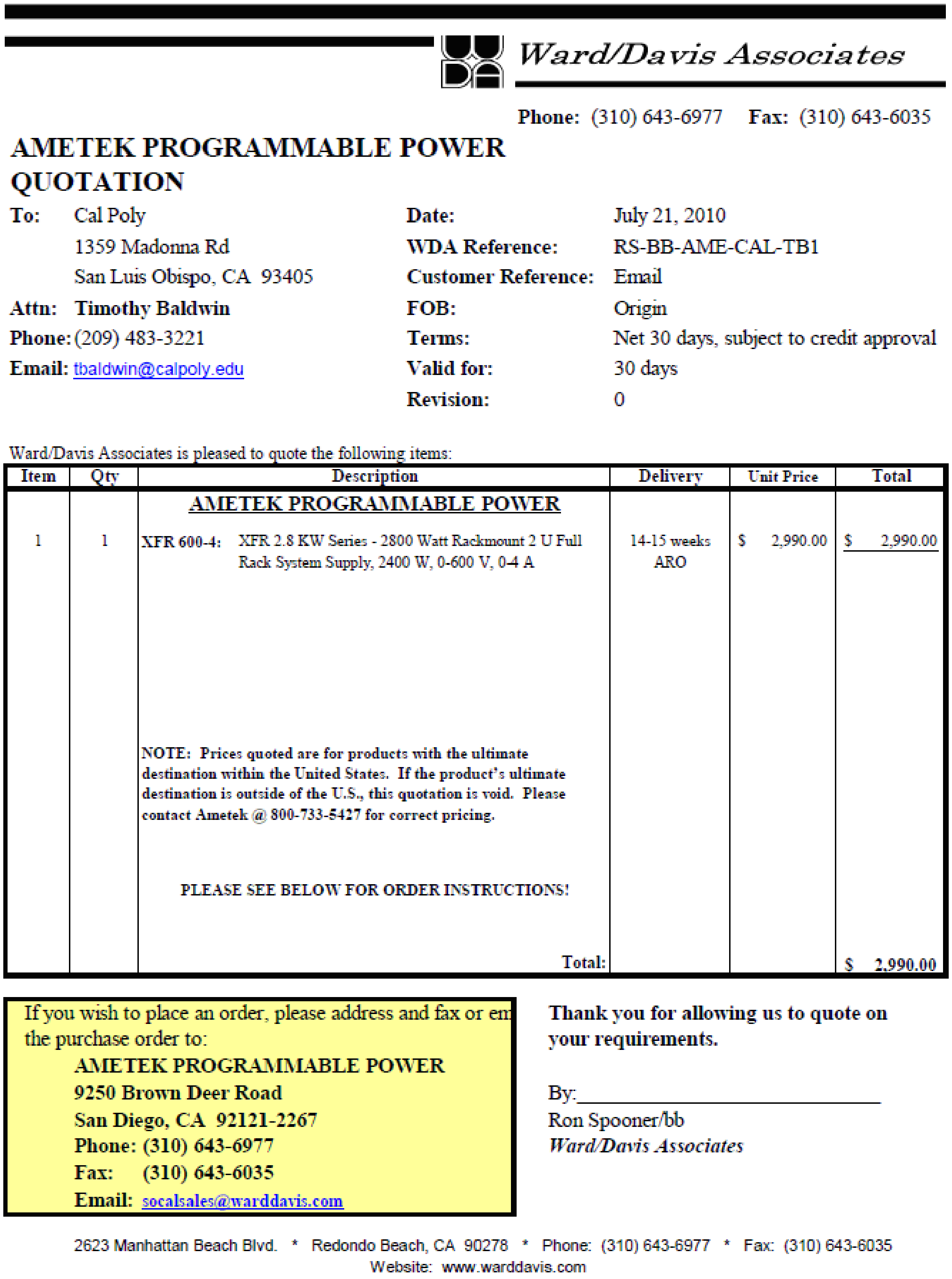
-L(240V)

-L(1P)

Input cable for AC1Ø (3-conductor type)

Input cable for AC3Ø

Appendix I: Power Supply Quote



Ward/Davis Associates

Phone: (310) 643-6977 **Fax:** (310) 643-6035

AMETEK PROGRAMMABLE POWER QUOTATION

To:	Cal Poly 1359 Madonna Rd San Luis Obispo, CA 93405	**Date:**	July 21, 2010
		WDA Reference:	RS-BB-AME-CAL-TB1
		Customer Reference:	Email
Attn:	**Timothy Baldwin**	**FOB:**	Origin
Phone:	(209) 483-3221	**Terms:**	Net 30 days, subject to credit approval
Email:	tbaldwin@calpoly.edu	**Valid for:**	30 days
		Revision:	0

Ward/Davis Associates is pleased to quote the following items:

Item	Qty	Description	Delivery	Unit Price	Total
		AMETEK PROGRAMMABLE POWER			
1	1	**XFR 600-4:** XFR 2.8 KW Series - 2800 Watt Rackmount 2 U Full Rack System Supply, 2400 W, 0-600 V, 0-4 A	14-15 weeks ARO	$ 2,990.00	$ 2,990.00
		NOTE: Prices quoted are for products with the ultimate destination within the United States. If the product's ultimate destination is outside of the U.S., this quotation is void. Please contact Ametek @ 800-733-5427 for correct pricing. **PLEASE SEE BELOW FOR ORDER INSTRUCTIONS!**			
		Total:			**$ 2,990.00**

If you wish to place an order, please address and fax or em
the purchase order to:

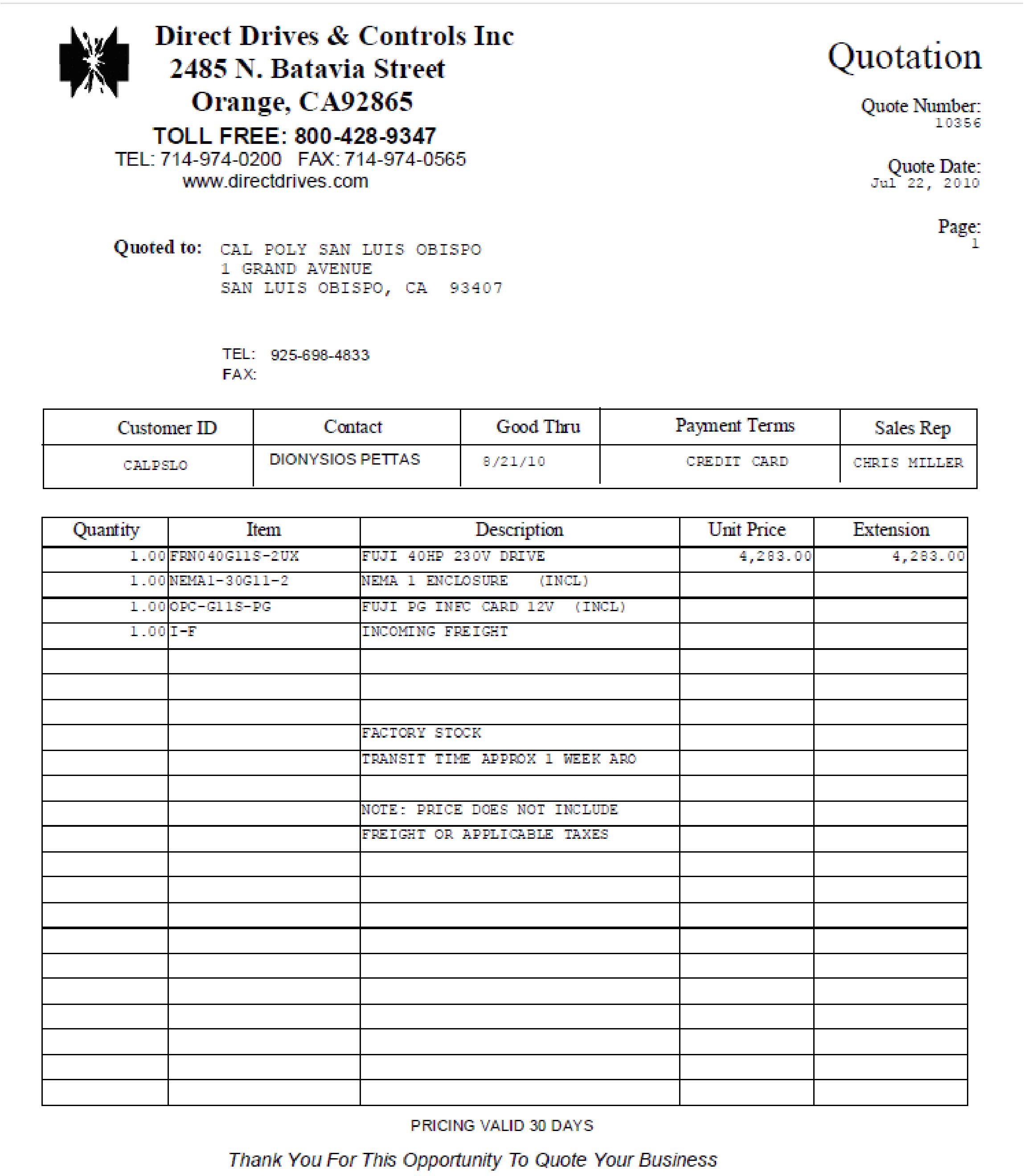
AMETEK PROGRAMMABLE POWER
9250 Brown Deer Road
San Diego, CA 92121-2267
Phone: (310) 643-6977
Fax: (310) 643-6035
Email: socalsales@warddavis.com

Thank you for allowing us to quote on your requirements.

By:________________________
Ron Spooner/bb
Ward/Davis Associates

2623 Manhattan Beach Blvd. * Redondo Beach, CA 90278 * Phone: (310) 643-6977 * Fax: (310) 643-6035
Website: www.warddavis.com

APPENDIX J: FUGI FRENIC VARIABLE FREQUENCY DRIVE QUOTE



Direct Drives & Controls Inc
2485 N. Batavia Street
Orange, CA92865
TOLL FREE: 800-428-9347
TEL: 714-974-0200 FAX: 714-974-0565
www.directdrives.com

Quotation

Quote Number:
10356

Quote Date:
Jul 22, 2010

Page:
1

Quoted to:
CAL POLY SAN LUIS OBISPO
1 GRAND AVENUE
SAN LUIS OBISPO, CA 93407

TEL: 925-698-4833
FAX:

Customer ID	Contact	Good Thru	Payment Terms	Sales Rep
CALPSLO	DIONYSIOS PETTAS	8/21/10	CREDIT CARD	CHRIS MILLER

Quantity	Item	Description	Unit Price	Extension
1.00	FRN040G11S-2UX	FUJI 40HP 230V DRIVE	4,283.00	4,283.00
1.00	NEMA1-30G11-2	NEMA 1 ENCLOSURE (INCL)		
1.00	OPC-G11S-PG	FUJI PG INFC CARD 12V (INCL)		
1.00	I-F	INCOMING FREIGHT		
		FACTORY STOCK		
		TRANSIT TIME APPROX 1 WEEK ARO		
		NOTE: PRICE DOES NOT INCLUDE		
		FREIGHT OR APPLICABLE TAXES		

PRICING VALID 30 DAYS

Thank You For This Opportunity To Quote Your Business