Canada-France-Hawaii Telescope Corporation

65-1238 Mamalahoa Hwy, Kamuela, Hawaii 96743 USA

Société du Télescope Canada-France-Hawaii

Telephone (808) 885-7944 Fax (808) 885 -7288

Dome Drive System Energy Savings Report

To: D.Salmon

Cc: C. Veillet, Executive

From: S.Bauman

Contributors: B. Cruise, I. Look, G. Matsushige, L.Roberts, J. Rodgers, R.Taroma

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Background

During the observatory automation project (OAP) the hydraulic dome drive system was selected as one of the sub-systems that required an upgrade to meet remote capabilities. Initially the project started out as a hydraulic upgrade project but after high costs of doing so were proposed, a feasibility study to find alternative methods was started. During the feasibility study, evidence was presented that pointed to a superior electric drive system which benefited from various returns; such as reduced maintenance and repair costs, reduced manpower resources, environmental and safety benefits, and reduced power consumption. The intent of this report is to provide a brief estimation of the electrical savings gained from the upgrade and a performance comparison regarding the electrical efficiency of the two systems.

Scope

Providing a single realistic number gain for the difference between the two systems, hydraulic and electric, is not as easy as it sounds. The complications first arise when you look at the data for nightly observations, each night the dome is rotated a different number of times, some nights the observatory is shutdown due to weather, therefore no rotations take place and other nights the observations require long exposures and some night's short ones. To complicate this further each dome rotation or move results in a different amount of rotation of the dome depending on the target and how far it is away from the last one observed. The amount of work required to provide accurate statistics is astonishing, and after much work it could still be inaccurate; therefore I will be comparing full (360˚) rotations of the dome, an operation both systems share identically at each commanded occurrence.

By comparing full dome rotations for each system, hydraulic and electric, the overall electrical consumption difference and efficiency gain can be clearly seen. This is basically an apples to apples comparison without the statistical complications. From the plot comparisons further below in the document, the following information can be collected. The data is listed in the chart below.

Before	Comparison Chart			
After	Hydraulic vs. Electric Dome Drive Systems			
	Avg Power Factor (unit less)		Average Real Power usage (Watts)	
	Idle	Slewing	Idle (ready-not moving)	Slewing (one full rotation)
Hydraulic	0.63	0.71	(P) 10,500 Watts	(P) 28,500 Watts
Electric	0.73	0.95	(P) 1450 Watts	(P) 6850 Watts

Table 1: Hydraulic and Electric dome drive system

Values listed are instantane ous values from plots	Comparison Chart			
	Hydraulic vs. Electric Dome Drive Systems			
	Average Apparent Power usage (Watts)		Overall Improvement	
	Idle (ready-not moving)	Slewing (one full rotation)	Idle	Slewing
Hydraulic	(S) 17,000 Watts	(S) 38,000 Watts		
Electric	(S) 1985 Watts	(S) 7250 Watts	8.5	5.2

Table 2: Hydraulic and Electric dome drive system improvement

The plots below are arranged to show the hydraulic system before the upgrade and the electric system after the upgrade. The plots have been scaled and fitted proportionally in an attempt to align the initial startup, idle time, and slewing occurrences. The only slight difference between the comparison plots is for the hydraulic drive system, four rotations are depicted, and on the electrical drive plots only three moves are illustrated. This should have no impact on the evaluation.

From plot 1 and 2 below the real power (P) or true power is plotted; the real power is the capacity of the circuit to perform work in a particular time. Without reference to the phase angle, it is the power needed for the required load with no losses at all in efficiently distributing the power to the system. Since the real power is basically the current and voltage of the circuit it is not fair to comment on the improvement during this process, but an overall energy reduction is noticeable.

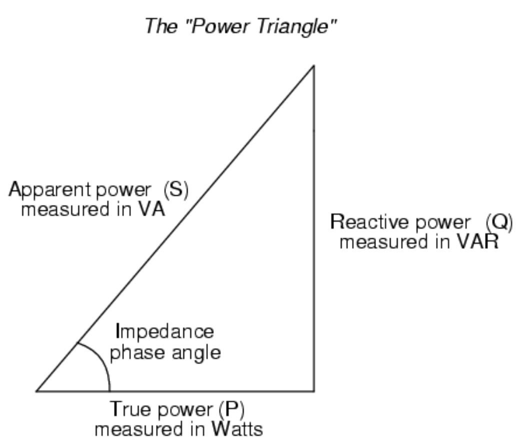

Figure 0: Power Triangle

In Plots 3 and 4 the apparent power (S) consumed is plotted, the apparent power is the product of the current and voltage in the system and includes line inefficiencies. Thus these plots include the line loss from the power factor. They show product of the real power and the power factor. The plots depict the increased energy needed for the load due to the fact that the circuit requires higher current due to the loss in the distribution system, it is the power drawn by the electrical resistance of the system performing work. This is the amount of overall energy we are billed for.

The average instantaneous values from the plots can be found in table 2. Note all values listed in the table are taken from the plots and do not directly reflect the product of the real power and power factor. The electric drive system reduced the electrical consumption of the system 8.5 times lower during idle and 5 times lower during slews. It is clear that the improvements stem from a reduction in energy consumption and also an improved power factor.

The power factor is illustrated in plots 5 and 6; it is the cosine of the phase angle (θ) between the voltage and current. Power factor is defined as the ratio of the real (true) power flowing to the load over the apparent power in the circuit. The dimensionless number reaches maximum efficiency or unity at 1, a high power factor reduces transmission losses and improves voltage regulation at the load.

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

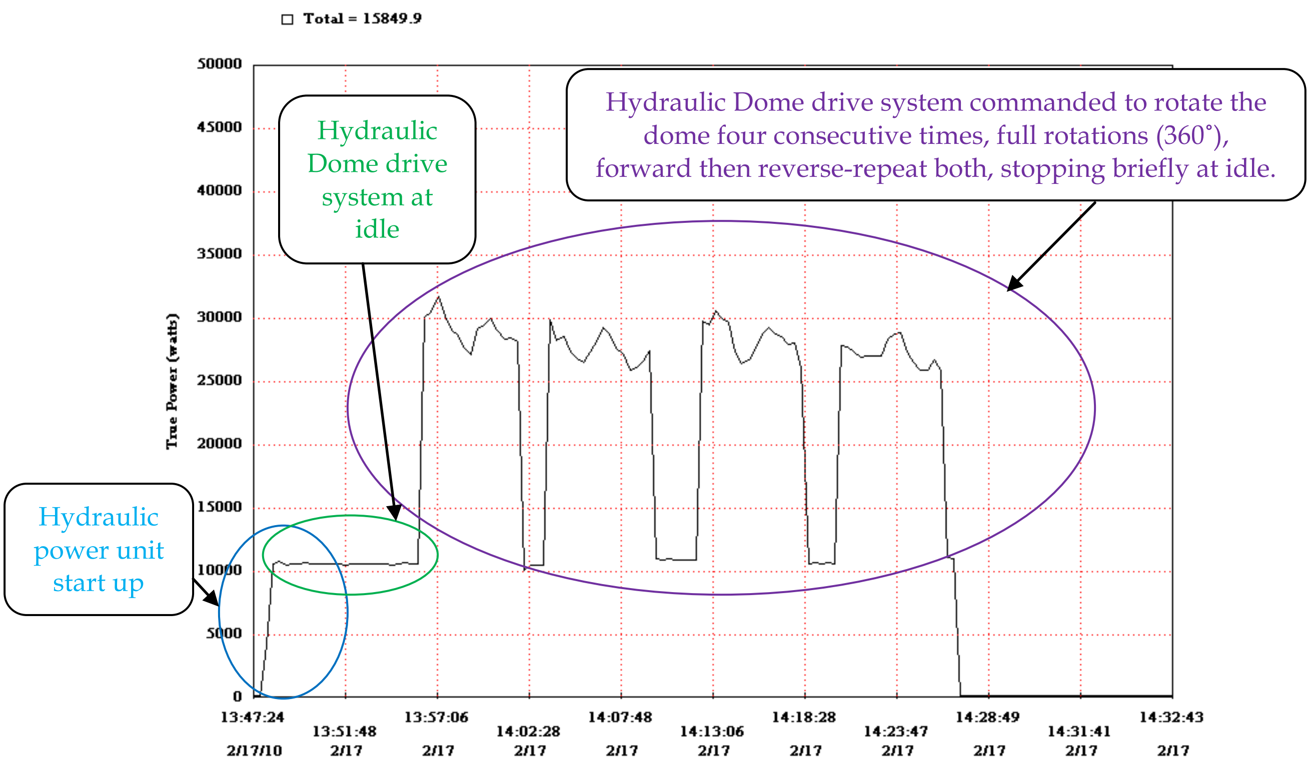

Figure 1: Hydraulic Dome Drive Power Unit survey - Real Power (watts)

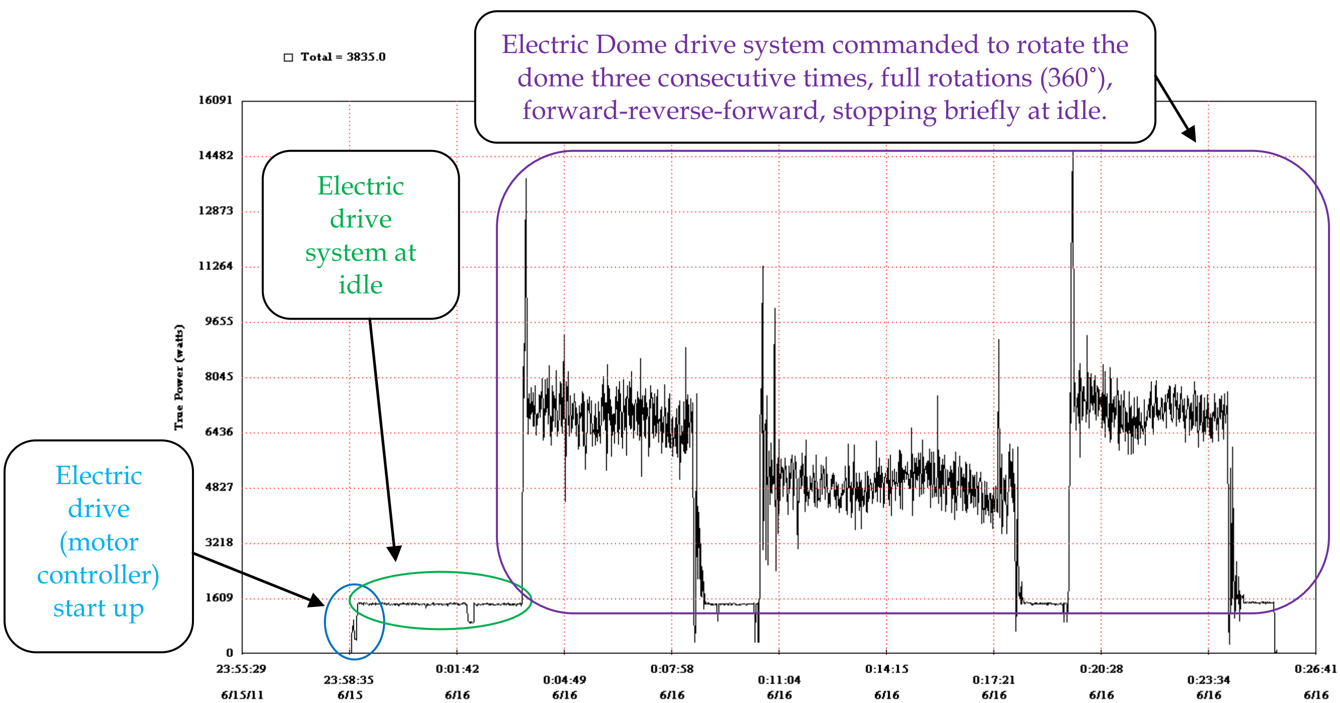

Figure 2 : Electric Dome Drive (VFD) survey - Real Power (watts)

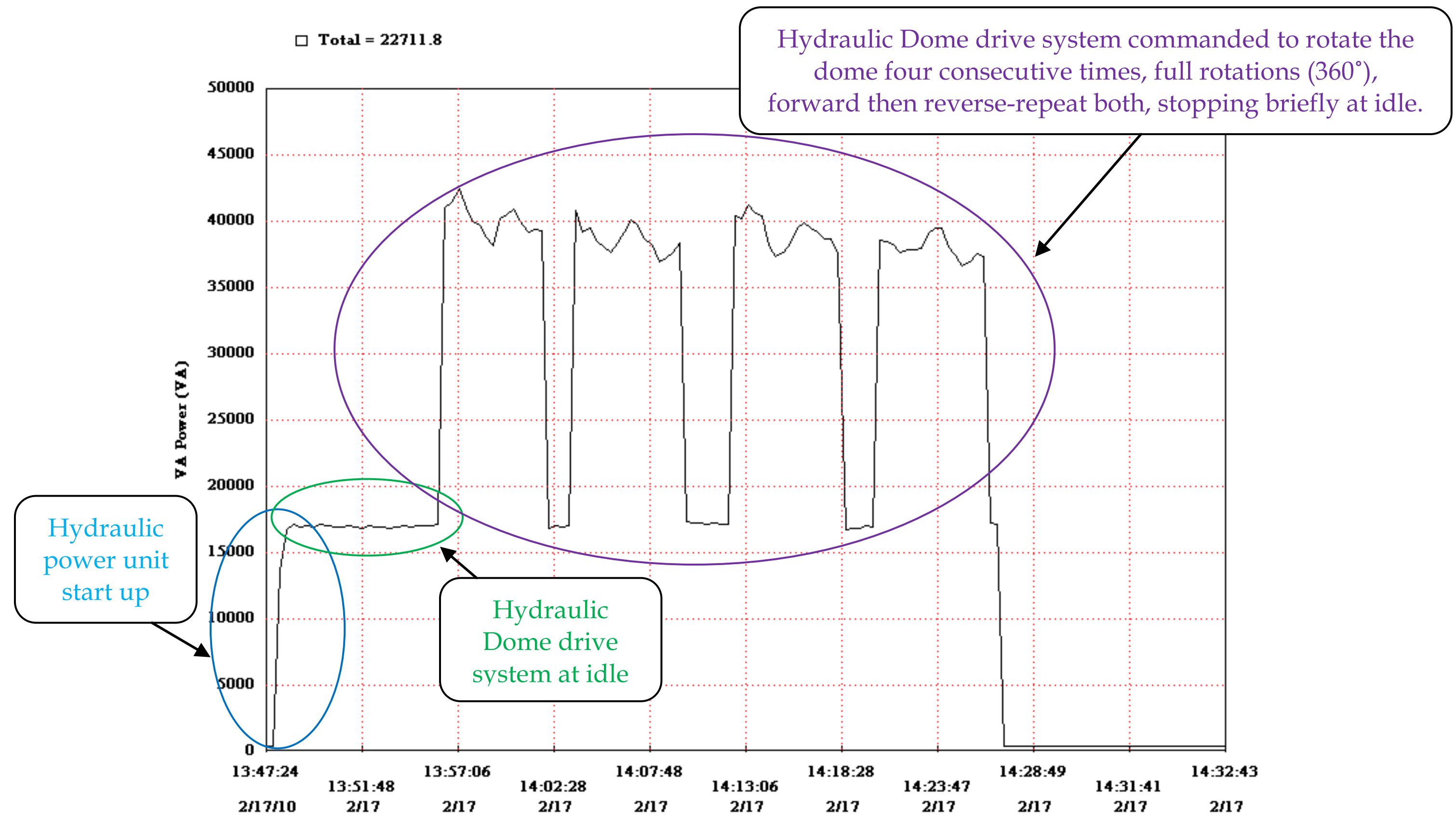

Figure 3: Hydraulic (Dome Drive) Power Unit survey - VA Power (VA)

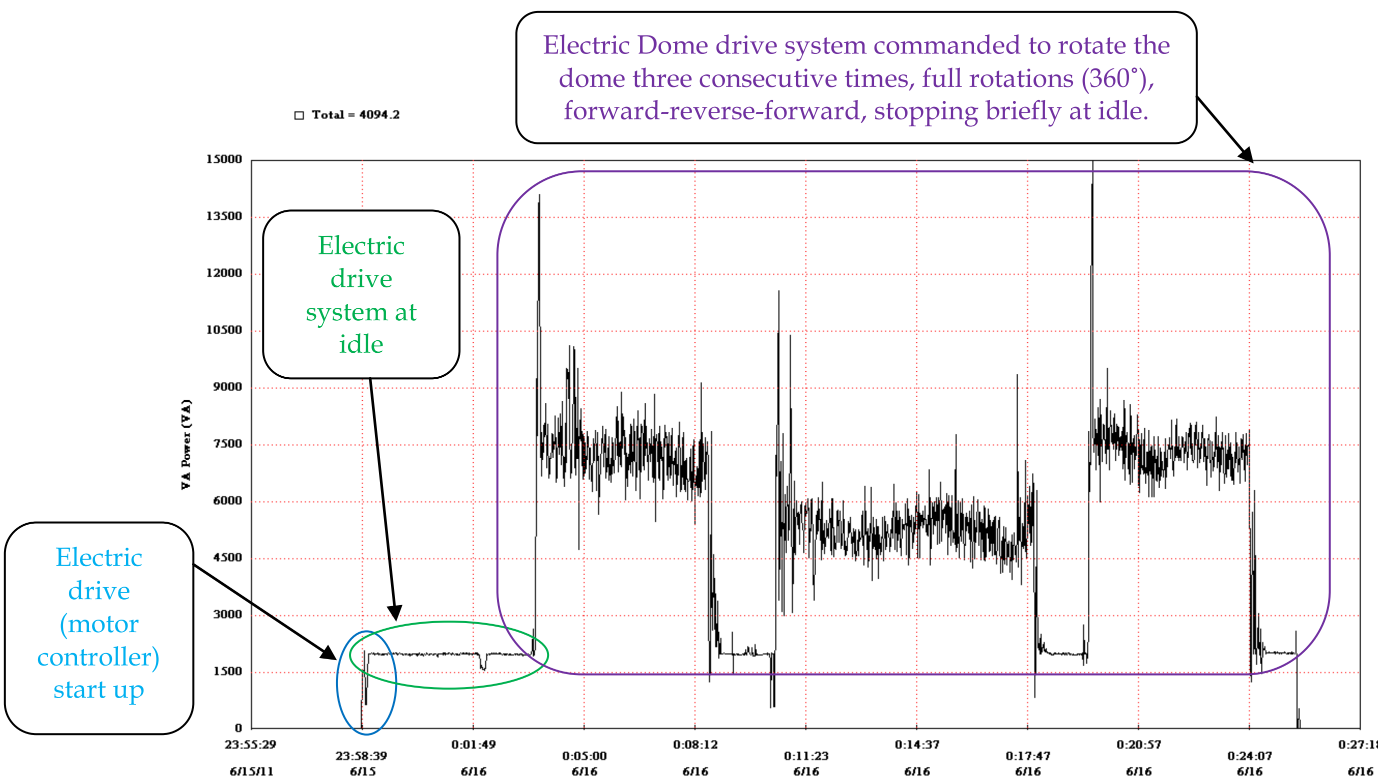

Figure 4: Electric Dome Drive (VFD) survey - VA Power (VA)

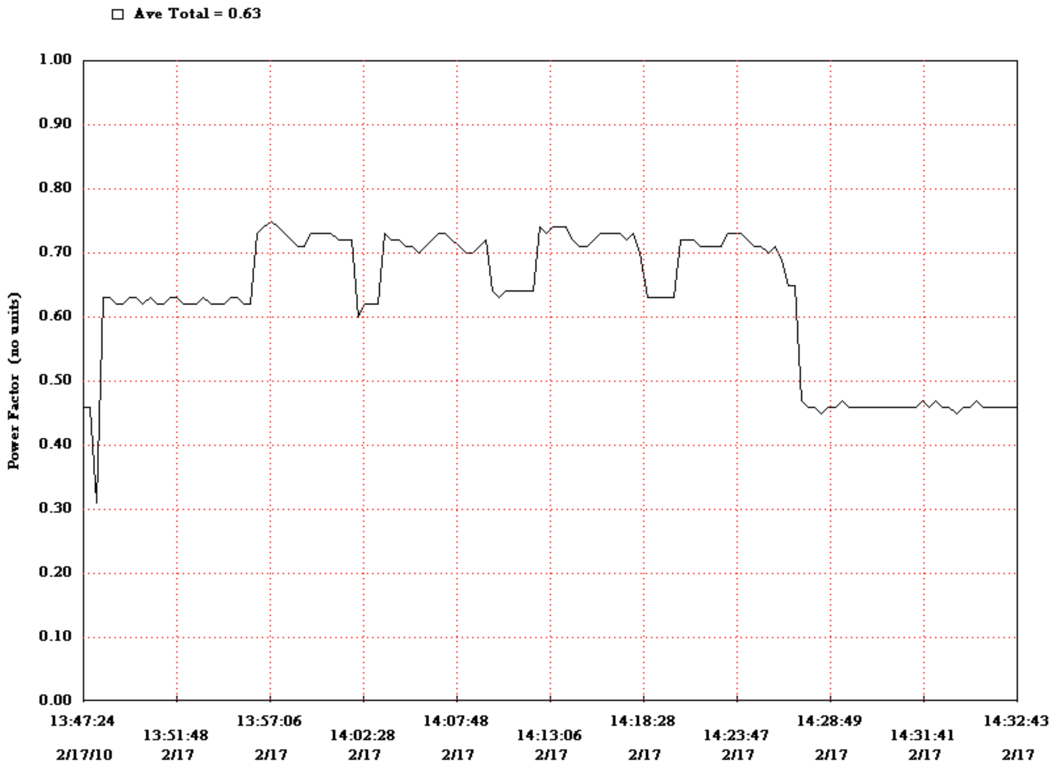

Figure 5: Hydraulic (Dome Drive) Power Unit survey - Power Factor (no units)

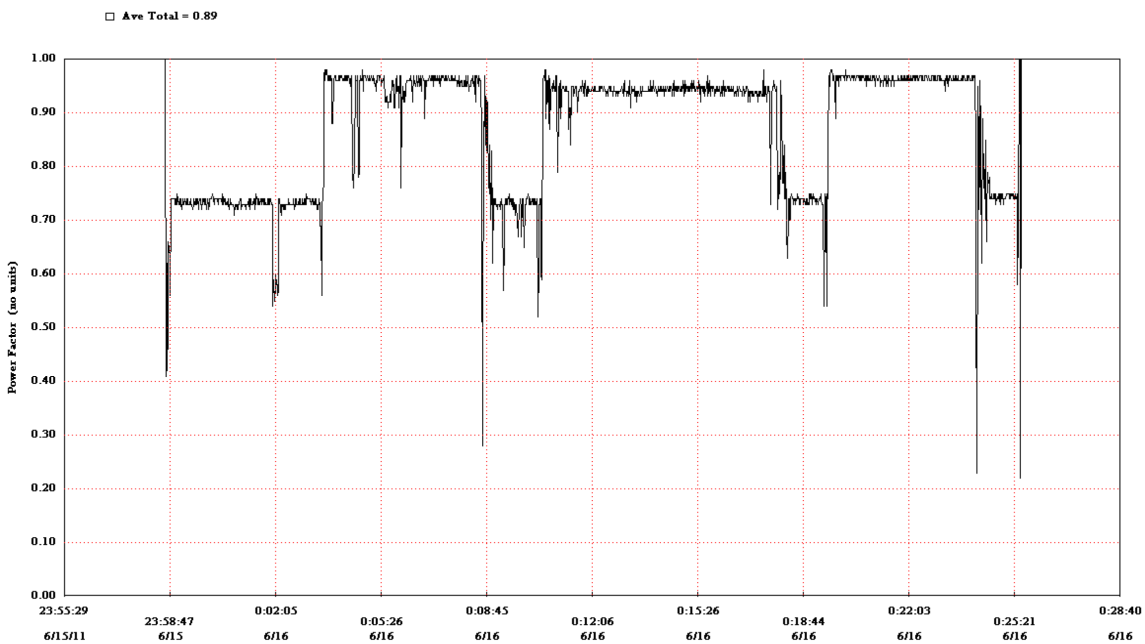

Figure 6: Electric Dome Drive (VFD) survey - Power Factor (no units)

In an attempt to determine the amount of time during the night that the dome is at idle or slewing, TCS engineer Bill Cruise was consulted. Using dome data collected nightly, an average operation time of 10.73 hours per night was estimated.

Dome Drive Operating Statistics					
Data obtained from TCS movements from Jan 1,2011 to Sept 26, 2011				*Manual control not included*	
	# of Nights	**MOVE**	**ON -Time**	**% move**	
	Total time - min	**9410.73**	**154556.42**	**6.09%**	
		156.85	**2575.94**		**hours**
	240	**0.65**	**10.73**		**hrs/night**
Hydraulic system	**Total time - min**	**3999.30**	**69308.07**	**5.77%**	**hours**
		66.65	**1155.13**		
	98	**0.68**	**11.79**		**hrs/night**
Electric system	**Total time - min**	**5317.43**	**83574.72**	**6.36%**	
		88.62	**1392.91**		**hours**
	140	**0.63**	**9.95**		**hrs/night**

Operation time refers to the start and end of observing for the night and hence the amount of time the drive system is operating. From estimations by Bill, during nighttime operation the dome is at idle 94% of the time, and slewing ~6% of the time. Fortunately the energy efficiency improvements for the dome drive bias a benefit during idle operations more so than slewing, this development was a surprise benefit or the new system.

The following plots are energy consumption plots from HELCO, Hawaii Energy Company, the provider of our electricity at the observatory. Plot 7 shows the amount of overall energy used for the entire building for a 24 hour period with the hydraulic dome drive system operated. The average observatory load during nightly operations is approximately 157 KW with a maximum load of 159.7 KW.

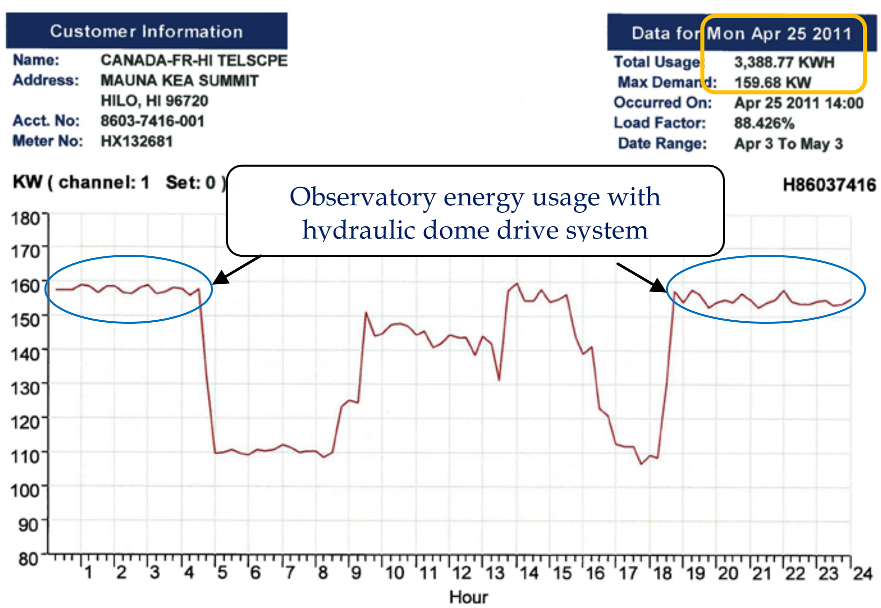

Figure 7: 24 hour energy profile for the observatory, April 25th

The next plot again depicts the overall energy usage for the entire observatory but now with the electric drive system operated during nightly observations. It is the very first night of operations with electric drive system, on April 28th, 2011, since no changes to other systems were made during the week, influences from other load demands or reductions should be negligible.

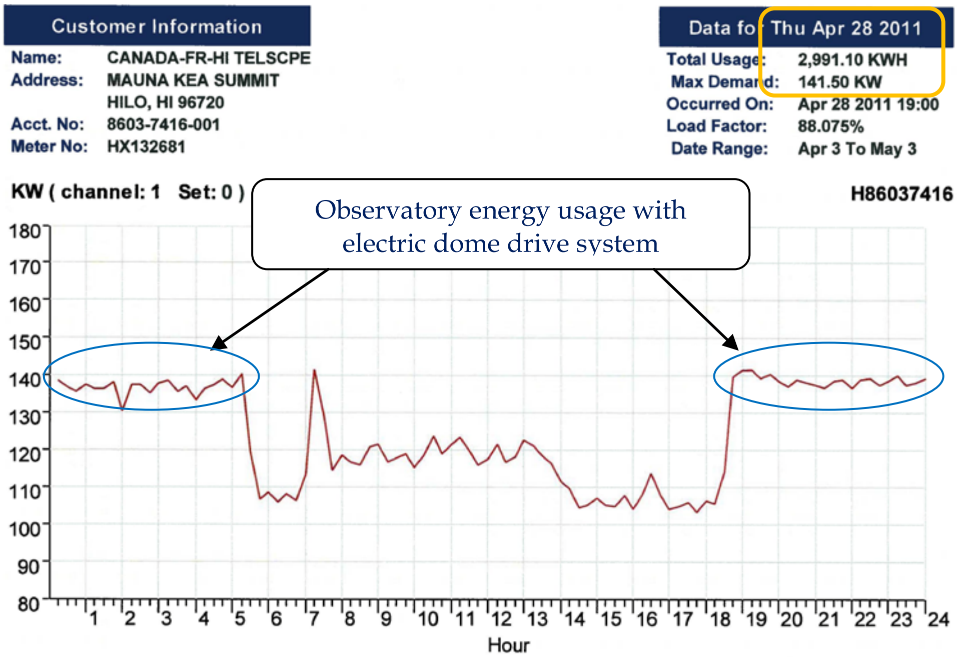

Figure 8: 24 hour energy profile for the Obs, April 28th

From plot 8 the overall energy reduction for the facility is discernible. The average observatory load during the nightly operations is approximately 138 KW with a maximum load of 141.50 KW. The difference between hydraulic drive and the electrical drive during operation are shown below in table 3.

Values listed are instantaneous values from plots	Comparison Chart			
	Hydraulic vs. Electric Dome Drive Systems			
	Overall Nightly Observatory Load (KW)		Energy difference (reduction)	Savings
	Average	Maximum	Average	Average
Hydraulic	157 KW	159.7 KW		
Electric	138 KW	141.5 KW	19 KW	12%

Table 3: 24 hour energy profile for the Obs, April 28th

<u>Conclusion</u>

The upgraded electric dome drive system has reduced the amount of energy consumed at the observatory during day and nighttime observations. It has also reduced the amount of maintenance required to maintain the system, eliminated hydraulic fluid leaks, freed up manpower, and provided a reliable remotely operated and monitored drive system. The cost of the electric dome drive upgrade was approximately $96,958.18, total budget costs for the upgrade were provided by J. Rodgers. The pricing from HELCO for our electricity at the summit ranges from $0.35-0.40 per KWH, but this is highly dependent on the peak demand charge in the last eleven months, which consequently the electric drive system has moved downward. But if one assumes a conservative average of $0.375 a KWH operating rate, a difference or reduction of 19 KW, and an average operating time of 11 hours each night. The dome drive system saves approximately ~$78.00 per average night. The telescope's nightly operations are highly dependent on weather and equipment failures, some estimates from C. Veillet, average the observatory down time due to weather (2%) and with technical problems combined for a total average of about 30%. That means only 255 nights out of the year the drive system is operating and therefore saves about $20k ($19,985) per year, therefore the upgraded electric drive system should pay for the costs of parts and materials to implement the system in 5-6 years or less due to conservative estimates. These savings do not take into account the costs for internal labor and salaries.