ALTERNATE POWER AND ENERGY STORAGE/REUSE FOR DRILLING RIGS: REDUCED COST AND LOWER EMISSIONS PROVIDE LOWER FOOTPRINT FOR DRILLING OPERATIONS

A Thesis

by

ANKIT VERMA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Petroleum Engineering

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Approved by:

Chair of Committee,	David Burnett
Committee Members,	Jerome Schubert
	Louise Darcy
Head of Department,	Stephen A. Holditch

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ABSTRACT

Alternate Power and Energy Storage/Reuse for Drilling Rigs: Reduced Cost and Lower Emissions Provide Lower Footprint for Drilling Operations. (May 2009)

Ankit Verma, B.Tech., National Institute of Technology, Bhopal

Chair of Advisory Committee: Prof. David Burnett

Diesel engines operating the rig pose the problems of low efficiency and large amount of emissions. In addition the rig power requirements vary a lot with time and ongoing operation. Therefore it is in the best interest of operators to research on alternate drilling energy sources which can make entire drilling process economic and environmentally friendly. One of the major ways to reduce the footprint of drilling operations is to provide more efficient power sources for drilling operations. There are various sources of alternate energy storage/reuse. A quantitative comparison of physical size and economics shows that rigs powered by the electrical grid can provide lower cost operations, emit fewer emissions, are quieter, and have a smaller surface footprint than conventional diesel powered drilling.

This thesis describes a study to evaluate the feasibility of adopting technology to reduce the size of the power generating equipment on drilling rigs and to provide "peak shaving" energy through the new energy generating and energy storage devices such as flywheels.

An energy audit was conducted on a new generation light weight Huisman LOC 250 rig drilling in South Texas to gather comprehensive time stamped drilling data. A study of emissions while drilling operation was also conducted during the audit. The data was analyzed using MATLAB and compared to a theoretical energy audit. The study showed that it is possible to remove peaks of rig power requirement by a flywheel kinetic energy recovery and storage (KERS) system and that linking to the electrical grid would supply sufficient power to operate the rig normally. Both the link to the grid and the KERS system would fit within a standard ISO container.

A cost benefit analysis of the containerized system to transfer grid power to a rig, coupled with the KERS indicated that such a design had the potential to save more than $10,000 per week of drilling operations with significantly lower emissions, quieter operation, and smaller size well pad.

DEDICATION

Firstly, I dedicate this thesis to Lord Shiva for giving me strength and will power.

To my parents, for their immense support and love

To my brother, for giving me moral strength

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the people who greatly contributed to the cause of this research: Mr. David Burnett, who is the chair of my graduate committee. He is always an inspiration, a person who always sees things ahead of time and is highly encouraging. I greatly appreciate him for trusting me always.

Thanks to other committee members; Dr. Jerome Schubert and Mrs. Louise Darcy for their time and support. I extend my thanks to Mr. Robert Van Kuilenberg of Huisman Itrec, USA, for his valuable technical guidance; Crisman participants for funding this project and making it feasible and Dr. Stephen Holditch, head of the Petroleum Engineering Department, who is a creator of opportunities for the students.

Thanks also to all my teachers for a world class masters degree experience; all my friends, officemates and classmates for their cooperation and to Texas A&M University for being such a wonderful home and alma mater. Finally, thanks to my entire family for their patience and love.

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1. INTRODUCTION

1.1 Overview

The rig power requirements vary a lot with time and ongoing operation. Therefore it is in the best interest of operators to research on alternate drilling energy sources which can make the entire drilling process economic and environmentally friendly. There are a lot of options available amongst renewable energy resources namely wind, solar, fuel cells and energy storage devices. Each of these has advantages and drawbacks in terms of economics or rig footprint. Research into alternate power systems both economically and practically feasible to modern oil and gas industry can be very useful. A system of electrical power grid in combination with an energy storage device such as a flywheel/super capacitor unit is one such source which can provide substantially cheaper energy as compared to diesel. This energy storage unit can supply/reuse the power above and below the base load and allow the rigs to draw the base load either from diesel engines or power grid and hence improve the drilling efficiency.

1.2 Current Problem

The drilling operation is like driving a car and putting its "pedal to the metal" for few seconds and releasing it totally again. Drillers seldom pay attention to the power consumption data making the entire drilling operation fuel inefficient. It is because either

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This thesis follows the style of *SPE Drilling and Completion.*

the rigs are not modern enough to capture each and every data point for all the installed actuators while in operation or the data is tight hole meaning it is kept confidential during the operation and is destroyed later. There is negligible effort by the industry to process the rig data in terms of power and energy consumption and improve drilling efficiency based on that actual data. Same is true for emissions data and rig footprint. The diesel engines give optimum performance only at a particular value of load. Intermittent power consumption of the rig poses problems for the diesel engines to reach that optimum load. The simultaneous power consumption of the rig has to be estimated and it is certainly not the sum of theoretical power rating of all the installed actuators (Huisman, 2005). A land rig's total power consumption is around 2 MW, all of which comes from diesel engines. These are low on fuel efficiency and produce harmful emissions because of cycle inefficiency or incomplete combustion (Kumar, Zheng 2008). Hence there is a growing need for developing an environmentally benign alternate power system which is economic and pragmatic. This study focus into various alternatives sources of energy storage and come up with a system design based on the best possible alternative source of energy storage/reuse available.

1.3 Objective

The goal of this project is to determine the feasibility of adopting technology to reduce the size of the power generating equipment and to provide "peak loading" energy through the use of new energy generating and energy storage devices.

This project is part of a larger Proposed GPRI/Crisman Study to develop theoretically and empirically an energy inventory of the drilling process from a rig perspective. There are a number of current technologies that can be used to partially provide power to a rig and reduce fuel consumption and emissions. These need to be evaluated technically and economically to determine the feasibility of application to a drilling rig (e.g., diesel additives, types of fuels (gas, dual fuel system, synthetic fuels etc, wind energy, solar cells, fuel cells, power management, and gas turbine generators). Together with these technologies, new energy storage technology (specifically energy storage compatible with drilling operations) will be required.

Investigation into two peak shaving technologies to be utilized in the drilling rigs namely flywheels and super capacitors for lightweight rigs. Super capacitors are potential sources of peak energy which can be instantly discharged to remove transients. Flywheels offer advantages of reliable operation, instant response, high efficiency, cost effectiveness and are environmentally friendly with minimal maintenance requirements (Rojas, 2003). After determination of cost involved for electrically operated rigs, work will be extended to specification, modeling and layout of electrical systems in the drilling rigs. This work involves design of a black box which will serve as a link between power grid and the rig and also incorporate the energy storage/reuse technology. Attempts will be made to optimize this design in terms of mobility, working efficiency and cost.

2. CHOICE OF ENERGY STORAGE DEVICE

2.1 Available Options

There are quite a number of devices which generate energy. This energy can later be stored. Solar panels, wind turbines, fuel cells, storage batteries, super capacitors and flywheels are some of the widely used devices. Apart from these there are also technologies which are under development phase. The above mentioned devices are considered viable for this project as they are used worldwide commercially. Energy is stored differently in all of these devices. In a wind turbine mechanical energy of wind is converted into electrical energy while in a fuel cell chemical energy is converted into electrical energy. Each of these energy storage devices is evaluated on the basis of following factors:

- Size.
- Economics.
- Power generating and storing capability in context of a drilling rig.
- Problems with installation and transport.
- Rig footprint.

2.1.1 Solar PV

A single solar cell unit produce approximately one watt of power. (www.eere.energy.gov). Solar cells have to be connected in series or parallel connection to obtain the desired value of power and the discussion of electrical connections of photo voltaic units is beyond the scope of this investigation. By using a solar calculator application designed by the U.S Department of Energy one can instantly come up with the cost of entire system in a particular area. The following system was designed which can provide power to only one of the mud pumps at full load.

Area	College Station
Solar Radiance	5.16 kWh/sq m/day
Average Monthly Usage	50,000 kWh
System Size	201.22 kW
Area Required	20122 sq ft.
Estimated Cost	$1,609,750 (www.findsolar.com)

Hence, it is economically and practically unrealistic to install such a large unit at the rig site. It increases rig footprint. Also it is difficult to transport. One other problem is its dependency on the sun which itself is subjected to intermittent availability. Also solar cells need a large battery house which again has the constraints of cost and mobility.

2.1.2 Wind Energy

The wind turbine converts wind energy into rotating motion of the blades. The turbine is linked with generators through a gear mechanism. The details of the design of wind turbine are beyond the scope of this investigation. But to have a practical picture following parameters are obtained from a previous "Environmentally Friendly Drilling" report.

Power Rating	750 kW (approximately the size of one of the generator unit)
Total weight	116 tones
Tower height	213 ft
Rotor Diameter	80 ft
Cost	$ 781, 940 (Rogers et.al, 2006)

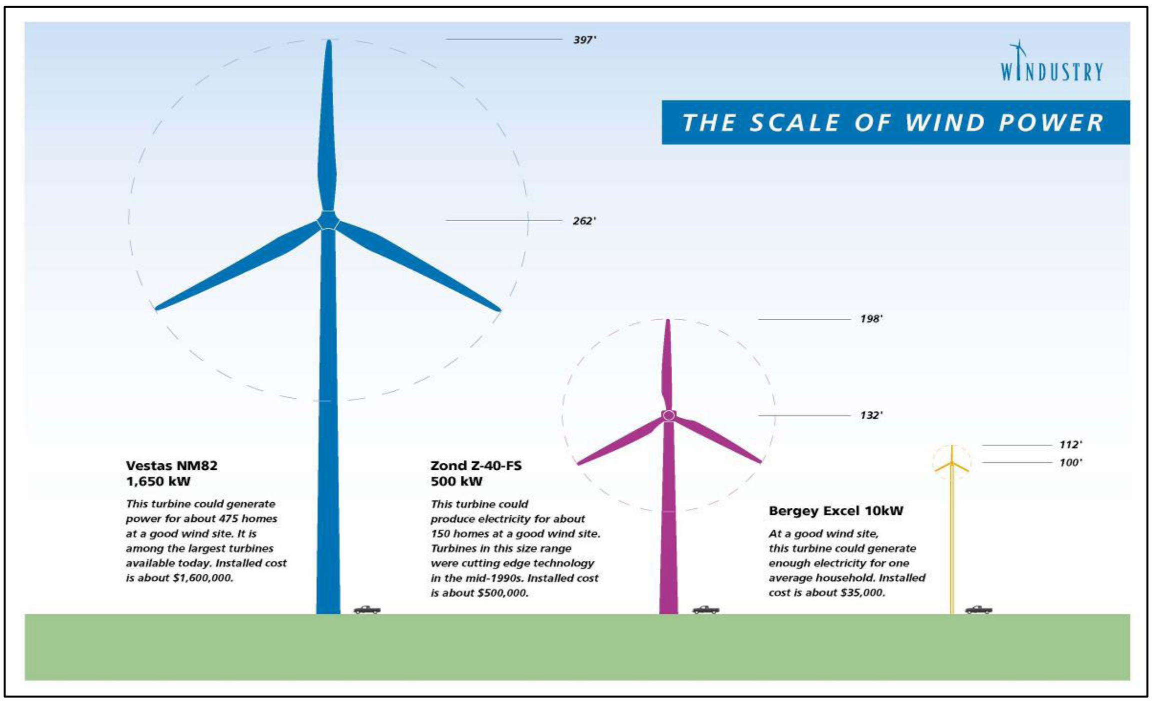

Figure 1 - Various sizes of wind turbines with their capital cost. (Rogers et.al, 2006) (Courtesy EFD Report).

Figure 1 shows the size variation of wind turbines with power. Hence due to larger rig footprint, transportation problems and high capital cost of investment with intermittent nature of power production this option is ruled out.

2.1.3 Fuel Cells

Fuel cells convert chemical energy into electrical energy. Electrical current is produced by providing gaseous fuels to anode and oxidizing the cathode which are porous (Parsons, 2000). Figure 2 shows working of fuel cell.

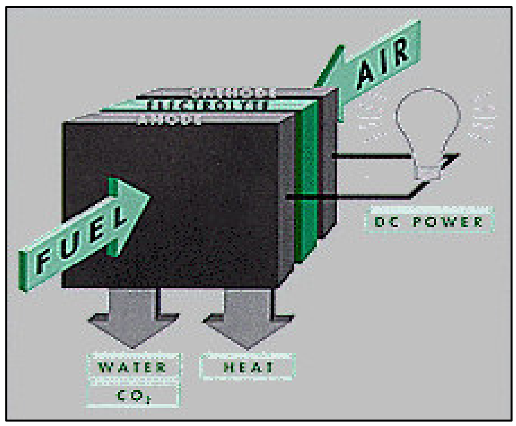

Figure 2 - Schematic of fuel cell. (Parsons, 2000) (Courtesy Fuel Cell Handbook).

Fuel cells have the advantages of no emissions and instant loading. They also do not produce noise. But it is the economics which is preventing the application of fuel cells in this project (Walsh, Wichert, 2008) Current prices range from $3000 to $4000/ kW. In addition there is an associated power system and maintenance cost. Although entire unit can be accommodated in reasonable size and provides reliable power.

2.1.4 *Storage Battery*

Storage battery unit is another viable option in terms of peak shaving. A stationary sulfur battery at an office park is set up in Ohio which can provide 100 kW of peak shaving for as much as 30 seconds which is considerably less than the rig requirements (Tamyurek and Nichols, 2003). Again the economics of the unit and battery life are restricting factors. In addition batteries fall more into low energy density systems which is not what is required in this project. This is because of the rig fluctuations which will cause the battery to partially charge and discharge hundreds of times in a day. It can adversely affect the battery life which is nearly 15 years or 2500 cycles of full charge and discharge with a cost of $164/ kW (Nichols and Eckroad). Even after a successful design the battery unit will be a separate entity which will add an extra container to the rig and hence additional transportation costs.

2.1.5 *Super Capacitors*

Super capacitors are used for supplying equipment with low power consumption

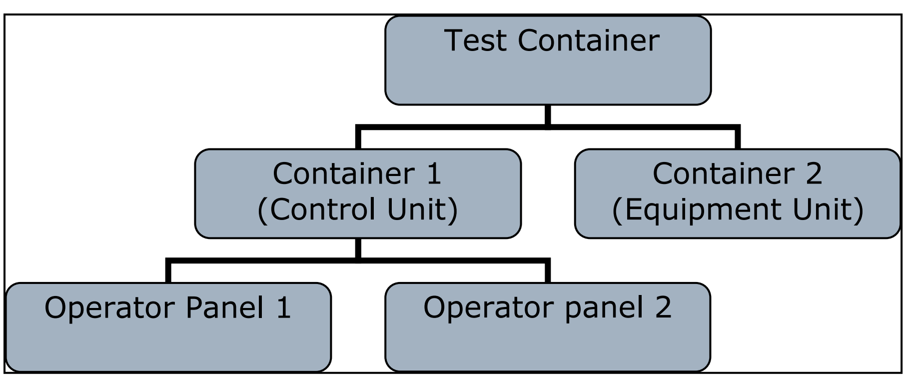

Figure 3 - Test set up of super capacitor unit.

and high current requirement with fast charging and discharging time. The test study of Huisman dealt with 10 modules of 43 capacitors 1500 Farad each (Palthe, 2008).

Figure 3 shows the test set up for super capacitors conducted by Huisman. The test would be conducted on a 30 kW motor with 5 seconds of hoisting for discharging and lowering for charging of the ultra capacitor unit. The electrical circuits with converters and their regulators, communication systems and detailed design of controllers are beyond the scope of this research. Table 1 shows the risks which are associated with this experimentation.

Table 1- Possible risks of testing super capacitor unit. (Courtesy Huisman Itrec).

Possible problem	Result	Solution
Voltage swing on the DC-bus to high at direct connection of the DC-DC converter	The inverter trips	Change to indirect connection of the DC-DC converter
Voltage too high on the DC-bus	The inverter trips	Adjust the chopper for this voltage level and dissipate energy in resistors
At indirect connected DC/DC converter, the switch over from step-up mode to step-down mode and visa versa at the wrong moment	The DC/DC converter trips and the Boostcap® Ultra-capacitor unit is not charged	Voltage range not sufficient, needs to be adjusted Monitoring by an external signal Change rectifier settings (parameters)

This pilot project is still under testing phase on a small scale of 30 kW and the results with cost benefit analysis are awaited. This technology has advantages of no noise, less maintenance and high performance. Therefore efforts are being made to extend it to drilling rigs.

2.1.6 Flywheels

Flywheels are proven technology for power regulation of telecommunication equipment and high power industrial equipment support. They offer advantages of reliable operation, instant response, high efficiency, cost effectiveness and are environmentally friendly with minimal maintenance requirements (Rojas 2003). Modern flywheel system rotates with high speed in vacuum with magnetic bearings. Flywheels are successfully tested for peak shaving in cranes.

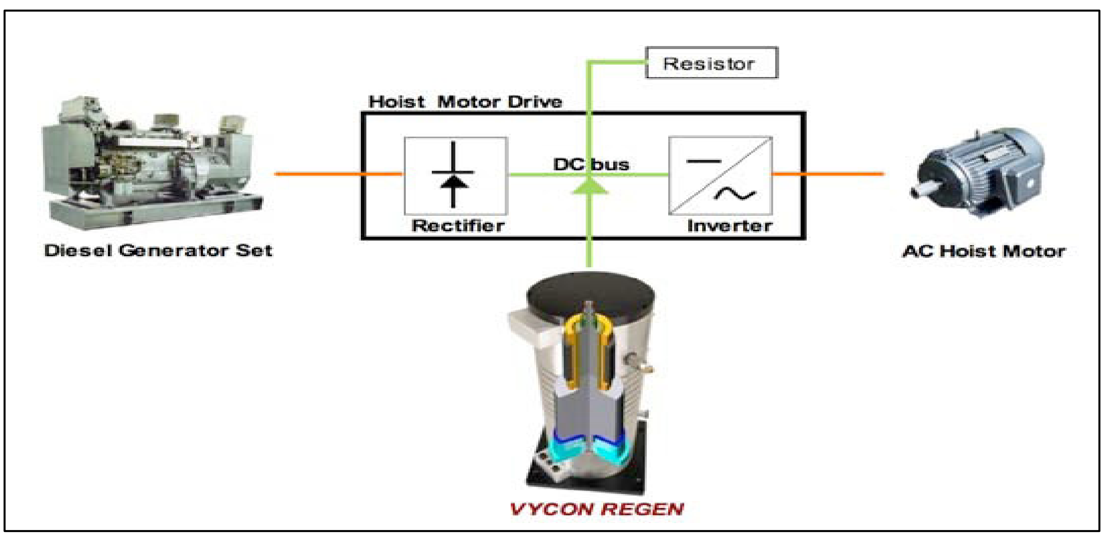

Figure 4 - Flywheel system coupled with crane's diesel engine. (Courtesy VYOCON).

One very promising example shown in Figure 4 was when a diesel generator was coupled with a flywheel it reduced the fuel consumption by as much as 38% (Romo et al., VYOCON).Flywheels are also a tested technology which can handle load in the range of rig's peak shaving values with virtually no maintenance cost. Also there is no limit to the number of charging and discharging cycles. Noise and emissions do not occur, not even lead poisoning like in case of storage battery. A look into commercially available flywheel units showed that they match the dimensions of ISO container along with the rest of the power system and can be easily transported. Hence flywheel unit was chosen to be the energy storage device for this project. Figure 5 compares cost of power quality for all the storage devices discussed above. Clearly flywheels also prove to be most economic.

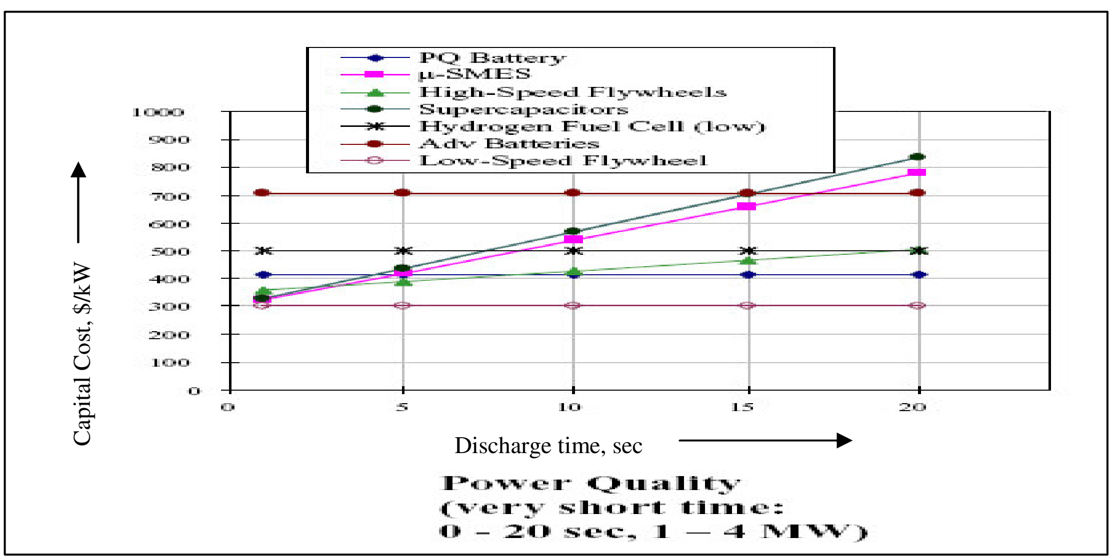

Figure 5 - Cost comparison of various technologies. (Courtesy: Sandia National Labs).

3. METHODOLOGY

3.1 Stepwise Procedure

1. Read various drilling rig manuals and understood the functioning of rig components and made a theoretical energy audit by identifying actuators based on nameplate specifications.
2. Visited a rig site in Texas for interviewing the service engineer and driller to understand the working and drawbacks of the rig for this new design and gathered comprehensive time stamped drilling data. Studied emissions produced while drilling operation.
3. Analyzed and comprehended this data using MATLAB for making an actual energy audit of the rig. Interview with flywheel expert at Texas A&M University was done to determine the specifications of flywheel unit.
4. Compared theoretical energy audit with actual audit and designed the optimized system followed by a cost benefit analysis to determine the return of investment.
5. Designed and encapsulated the power system into the size constraint of ISO container.
6. Studied diesel engines performance curves to determine exact load which the energy storage unit has to provide for effective peak shaving.

3.2 Drilling Rig Study

Land Offshore Containerised (LOC) rigs are casing while drilling rigs which offer a number of advantages like faster drilling time, safe and efficient operation, very little or no trip time, offline BOP testing, less energy requirement for drilling operation, highly automated control system and fewer crew members (Huisman, 2005) . The study was conducted on this rig because it has a sophisticated supervisory control and data acquisition (SCADA) system monitoring various drilling parameters.

Figure 6 – LOC 250 rig in actual field.

A set up of LOC 250 rig in the field is shown in Figure 6. Additionally these are ISO containerised rigs which means they are easy to relocate and transport. LOC 250 (Land and Offshore Containerized Unit, hook load 250 tonnes) contains 17 containers while LOC-400 (Land and Offshore Containerized Unit, hook load 400 tonnes) consist of 16 containers (Huisman, 2005). These are the two Casing While Drilling (CWD) rigs under consideration in this study. Table 2 provides description of various containers of LOC 250. A comprehensive energy audit of both of these rigs is done in order to determine the overall power and energy these rigs consume and also the values of transient power peaks which should be provided by our alternate power system. For this purpose time stamped data from one of the LOC-250 rig was obtained and processed. LOC-400 is a successor of LOC-250 and it is assumed that the processed values from LOC-250 will match closely to that of LOC-400. This is because LOC-400 is an improved version of LOC-250 and is still under construction. Hence operational data from LOC-400 is unavailable. Nonetheless theoretical energy audit of LOC-400 is done in this study.

Table 2- Container description for LOC 250. (Courtesy Huisman US Inc.).

Short	Name	size	Description	[mton]	[sht]
BASE	Base container	40’	Stabilizers, rig up winch, erection frame	36	40
DWK	Drawworks container	20’	Drawworks, reeving winch, wire line winch	36	40
MP1	Mud pump 1 container	20’	Mud pump, electrical distribution panel	30	33
MP2	Mud pump 2 container	20’	Mud pump, rig up hydraulic power unit, emergency electrical power unit	30	33
BOP	Blow Out Preventor container	20’	BOP, trip tank, BOP hoist system	30	33
MLS	Mast Lower Section	40’	Rotary table with power slips, standpipe manifold	30	33
MMS	Mast Middle Section	40’	Top drive, service loop, kelly hose, large floodlights	30	33
MCS	Mast Crown Section	40’	Service crane, tuggers	30	33
PH	Pipe Handler	40’	Pipe handler	28	31
PR	Pipe Rack	40’	Two tilting piperacks	20	22
DC	Drillers Cabin	40’	Water tank, water pumps, high pressure cleaner, driller’s cabin	30	33
PU	Power Unit	40’	Electrical generator set, main electrical distribution, two diesel engines with hydraulic pumps, hydraulic tank, hydrau-lic coolers, electrically driven constant pressure pump	36	40
ATM	Atmospheric degasser	20’	Atmospheric degasser, choke manifold, coarse scalping shakers	25	27.5
AMC	Active Mud Container	40’	Active tank, sand trap, fine screen shak-ers, charge pumps, vacuum degasser, agitators, level sensors, manifolds	25	27.5
MMC	Mud Mix Container	40’	Reserve tank and pill pits, shear mixer hopper, mix pumps, agitators, caustic barrel	25	27.5
ACCU	Accumulator	40’	BOP control unit, BOP test pump, air compressor and dryer, tool room/ workshop, oil storage	28	31
FUEL	Fuel container	20’	Fuel tank with transfer pump	15	16.5

3.2.1 Electrical System for LOC-400

The main power consumers namely mud pump, drawworks and top drive of LOC-400 rig are mounted on the main dc bus. There are two or three diesel generators with total rated power of 2400 KW, 480 V, 60 Hz, 3000 KVA. Two transformers convert this into 690 V, 60 Hz and feed it to the invertors which then convert it into DC and supply to the main bus where all major consumers are mounted. Regenerated power is dissipated in the brake resistors. The single line diagrams for LOC 400 with bus bars and different actuators and is shown in Figure 7. A close look at the boxes connected to the main bus shows the two transformer containers which basically forms the alternate power system. The details of these containers will be described later.

According to Huisman specification manual for LOC-400, it should not be difficult for the rig to take power from the utility grid. If there are strong reasons in terms of cost savings and efficiency, such a possibility should be thoroughly explored.

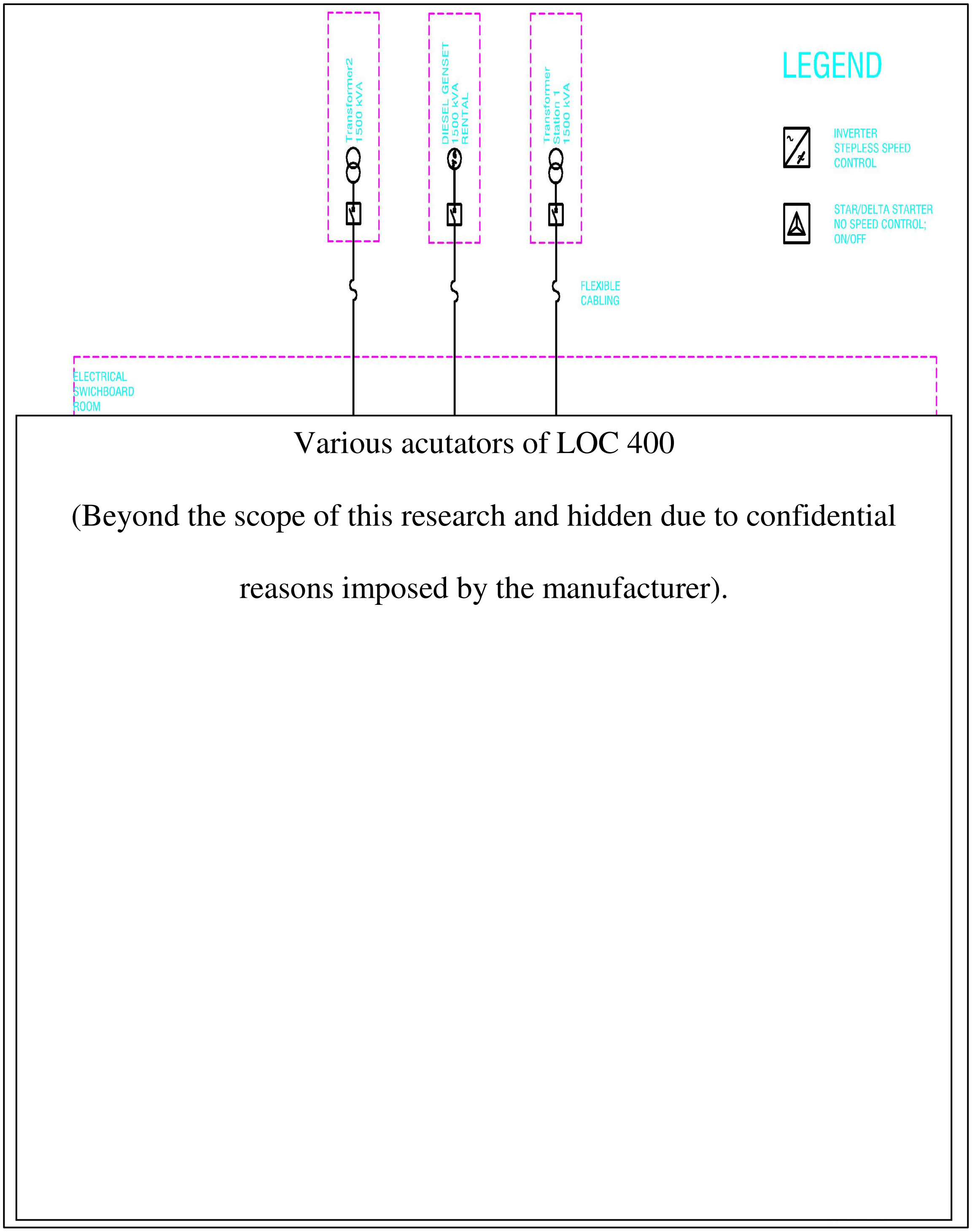

Figure 7 – Single line diagram of LOC 400 with alternate power system.

3.2.2 Electrical System for LOC-250

There are two generators feeding the 480 V main bus which itself feeds the hydraulic power unit (HPU) and one generator feeding electrical power unit (EPU). Variable frequency drives are mounted in order to attain different speeds. There are no invertors feeding the main power consumers rather they are AC motors as opposed to LOC-400. The hydraulic power system in LOC-250 is replaced by electrical system in LOC-400 which is the reason why it is considered to be a better version of LOC-250. Also this is one of the reasons why there is no efficiency loss in LOC-400 when converting the regenerative power from hydraulic to mechanical and then electrical which is the case with LOC-250. The single line diagram for LOC 250 with bus bars and different actuators in place is shown in Figure 8. Some of the actuators installed are not shown in the single line diagram because of confidential reasons. However they do not pertain to the scope of this project and hence not required by the reader to know.

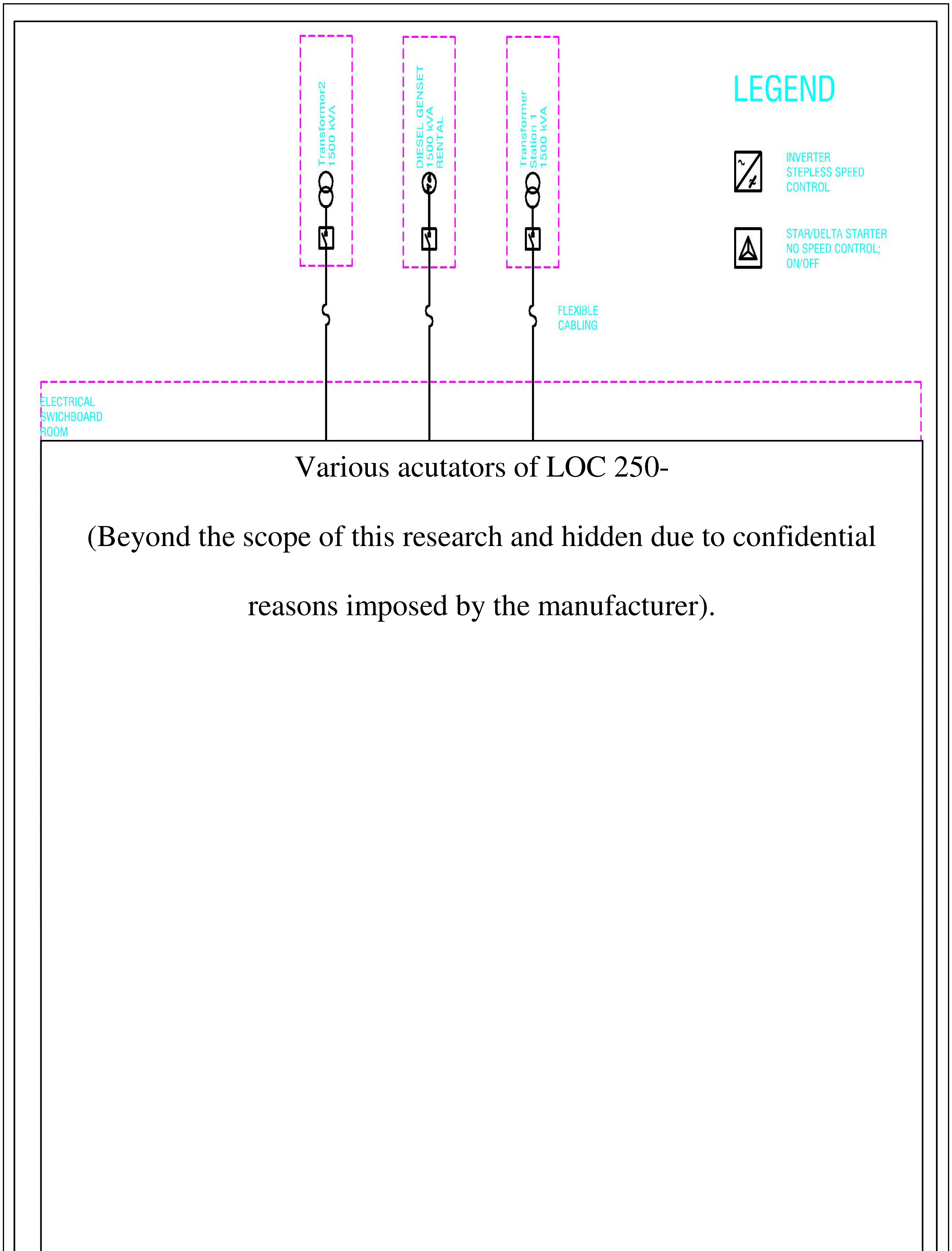

Figure 8 – Single line diagram of LOC 250 with alternate power system

3.3 Energy Audit

3.3.1 Theoretical Energy Audit

The rig does not operate on its full rating all the time. Rather the power consumption is distributed as given by Table 3. Initially a theoretical energy audit for the rig was conducted based on the specifications of the rig. This was done by reading various nameplate ratings of the drives installed on the rig. For hydraulic system power was calculated based on the flow multiplication by pressure ratings in the hydraulic diagrams. Hydraulic drives are mainly mounted on LOC 250 rig.

Table 3- Simultaneous power consumption of the rig with operating time. (Courtesy Huisman US Inc.).

Share Load of Engines	Operating Time
75%	60%
50%	30%
10%	10%

Table 4 exhibits the theoretical values of rig specifications for various actuators. Hence design of this KERS system based on theoretical energy audit will simply result in an overly designed system which will be uneconomic and underutilized. Therefore an actual energy audit of LOC-250 is required.

Table 4 – Theoretical Energy audit of LOC 250 with various actuator ratings.

Main Power Consumers	**Power in kW**	**No.**
Drawworks	2X400	2
Mudpump	3X400	3
Topdrive	1X440	1
Wire line traction	2X55	2
Wire line storage	2X25	2
Total installed Power	2578	
Maximum simultaneous Power Consumption	1600	
Secondary Power Consumers		
Shaker	2X3	2
Degasser	18.5	1
Agitator	12X5.5	12
Centrifugal Pumps	3X55	3
Mud Pump liner wash pump	tbd	
BOP control Unit	15	1
Hydraulic Power Unit	2X110	2
Compressors	15	
Miscellaneous	tbd	
Total Installed Power	500	
Max Simultaneous Power Consumption	400	
Hydraulic Drives	2X110	2
Rig Up and Emergency Diesel Pump	40	1

3.3.2 Actual Energy Audit

To obtain a realistic measure of power consumption an actual audit of the rig is required. This can be done by processing real time operational rig data. The process starts with gathering the rig data from its SCADA system. This data can be converted to comma separated format by the use of Trend Reader software. These comma separated files after a little conditioning can be imported to MATLAB. There were as much as 23 rig parameters obtained from SCADA system. Each of these parameters was as much as 1.3 million lines long. Excel can process data only a little more than 65000 lines. Hence a comprehensive tool with multiple functionalities was required. This is the reason why MATLAB was chosen for this research. Table 5 shows various rig parameters. The highlighted parameters were those signals which were later combined in MATLAB for obtaining relevant results.

Table 5 – List of SCADA signal measured on LOC 250

Title	Total Headers	Start	End	Continuous	Sample Time(sec)
Gas Units	51	06-25-07,00:00:00	06-22-2008,23:59:59	Yes	0.5
Auxiliary Pressure	51	06-25-07,00:00:00	06-22-2008,23:59:59	Yes	1
Bit Location	51	06-25-2007 00:00:00	06-22-2008,23:59:50	Yes	10
Block Position	51	06-25-2007 00:00:00	06-22-2008,23:59:59	Yes	1
Depth	51	06-25-2007 00:00:00	06-22-2008,23:59:50	Yes	10
Dexponent	51	05-28-2007 00:00:00	05-25-2008 23:59:50	Yes	10
Flow Bell Nipple	51	05-28-2007 00:00:00	06-22-2008 23:59:58	Yes	2
GainLoss	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
HookLoad	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
MudPump1GPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
MudPump1SPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
MudPump1Total strokes	51	04-06-2007 00:00:00	01-06-2008 23:59:58	Yes	2
MudPump2GPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
MudPump2SPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
MudPump2Total strokes	51	04-6-2007 00:00:00	01-06-2008 23:59:58	Yes	2
PillTank1Volume	51	06-18-2007 00:00:00	06-15-2008 23:59:50	Yes	10
PillTank2Volume	51	06-18-2007 00:00:00	06-15-2008 23:59:50	Yes	10
Pipe Velocity	51	06-25-2007 00:00:00	06-22-2008 23:59:50	Yes	10
Pit Volume Total	51	06-18-2007 00:00:00	06-15-2008 23:59:58	Yes	2
Pump Pressure	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
Rate of Penetration	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
ReserveTankVolume	51	06-18-2007 00:00:00	06-15-2008 23:59:50	Yes	10
RotaryTableRPM	51	06-25-2007 00:00:00	06-22-2008 23:59:50	Yes	10
RotaryTableTorque	51	06-25-2007 00:00:00	06-22-2008 23:59:50	Yes	10
ShakerTankVolume	51	06-18-2007 00:00:00	06-15-2008 23:59:50	Yes	10
SICP	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
SuctionTankVolume	51	06-18-2007 00:00:00	06-15-2008 23:59:50	Yes	10
TopDriveRPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
TopDriveTorque	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
TotalGPM	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2
TotalStrokes	51	01-6-2008 23:59:00	05-21-2007 00:00:00	Yes	10
TripTankVolume	51	06-18-2007 00:00:00	06-15-2008 23:59:58	Yes	2
WeightOnBit	51	06-25-2007 00:00:00	06-22-2008 23:59:59	Yes	0.5
WireLineDepth	51	11-6-2007 00:00:00	06-15-2008 23:59:58	Yes	2
WireLineLoad	51	06-25-2007 00:00:00	06-15-2008 23:59:58	Yes	2
WireLineSpeed	51	06-25-2007 00:00:00	06-22-2008 23:59:58	Yes	2

3.3.3 MATLAB Code

The following procedure was followed in MATLAB:

- [date,time,mp1gpmdatadata]=textread['C:\Users\ankit\Desktop\Signal combination\MudPump1GPM.txt','%s%s%n'];
- [date,time,ppdata]=textread['C:\Users\ankit\Desktop\Signal combination\PumpPressure.txt','%s%s%n'];
- %Delete date and time for both of the above
- plot(mp1gpmdata);
- plot(ppdata);
- mppower=mp1gpmdata.*ppdata;%point wise vector multiplication
- plot(mppower);
- mpmv=filter(ones(1,2)/2,1,mppower);%Moving Average for 2 seconds
- plot(mpmv);%Plotting moving average curve
- z=[1:1330000]%defining a column vector z
- z=z';
- plot(z,mppower,z,mpmv);%plotting original curve VS moving average curve
- mpdifference=mppower(2:1330000,1)-mpmv(1:1329999,1);%Calculating the difference between the two curves with 2 seconds lag
- plot(mpdifference*.0063);%plotting difference between original signal and moving average on KW scale
- mpdifference1=mpdifference(4e5:6e5)%segmenting a part of 'difference'
- mpdifference1=mpdifference1*.0063%converting into KW scale

- mpenergy1=filter(ones(1,200001)/1,1,mpdifference1);%adding Nth value to all (N-1) values for obtaining energy curve
- %Entire procedure is repeated for top drive with a conversion factor of .00010046
- plot(mpdifference(1:1309725)+mp2difference(1:1309725)+tddifference);%plotting total difference of power for mud pump1,mud pump2 and top drive which the flywheel has to supply(2 sec)
- plot(z(200001:400001),mpenergy1,z(400001:600001),mpenergy2,z(600001:800001),mpenergy3);%Plotting overall energy for mud pump1
- %Remove the offset from above curve
- plot(z(200001:400001),mp2energy1,z(400001:600001),mp2energy2,z(600001:800001),mp2energy3);%Plotting energy for mud pump2
- %Remove the offset from above curve
- plot(z(200001:400001),tdenergy1,z(400001:600001),tdenergy2,z(600001:800001),tdenergy3);%Plotting cumulative energy for top drive
- % Remove the offset from above curve
- plot(mpdifference(1:1309733)+mp2difference(1:1309733)+tddifference);%Plotting total difference of power for mud pump1,mud pump2,top drive for 2 sec
- plot(z(200001:400001),mpenergy1,'b',z(400001:600001),mpenergy2,'b',z(600001:800001),mpenergy3,'b',z(200001:400001),mp2energy1,'g',z(400001:600001),mp2energy2,'g',z(600001:800001),mp2energy3,'g',z(200001:400001),tdenergy1,'y',z

(400001:600001),tdenergy2,'y',z(600001:800001),tdenergy3,'y');%Comparing energy curves for mud pump1,2 and top drive

- plot(z(4e5:6e5),mp2energy1+mpenergy1+tdenergy1,z(6e5:8e5),mp2energy2+mpenergy2+tdenergy2,z(8e5:10e5),mp2energy3+mpenergy3+tdenergy3);
- grid %Adding energy curves for mud pump1,2 and top drive
- %maximum value of cumulative energy curve for 2 sec=550KJ; Including an efficiency factor of 0.7 for the entire system E_{max}*(flywheel)=785 KJ*
- %maximum value of difference of power curve for 2 sec =100 KW; Including an efficiency factor of 0.7 for the entire system P_{max} *(flywheel)=143 KW*
- %entire procedure is repeated for window period of 10 seconds
- %maximum value of cumulative energy curve for 10 sec=20000KJ;Including an efficiency factor of 0.7 for the entire system E_{max} *(flywheel)=28570 KJ*
- %maximum value of difference of power curve for 10 sec =140 KW; Including an efficiency factor of 0.7 for the entire system P_{max} *(flywheel)=200 KW*
- %entire procedure is repeated for window period of 20 seconds
- %maximum value of cumulative energy curve for 20 sec,=86000KJ;Including an efficiency factor of 0.7 for the entire system E_{max} *(flywheel)=122857 KJ*
- %maximum value of difference of power curve for 20 sec=152 KW; Including an efficiency factor of 0.7 for the entire system P_{max} *(flywheel)= 217 KW*
- plot(z(200001:400001),mpenergy1,z(400001:600001),mpenergy2,z(600001:800001),mpenergy3,z(200001:400001),tdenergy1,z(400001:600001),tdenergy2,z(60

0001:800001),tdenergy3)%Comparing Cumulative Energy Curves for Mud Pump and Top Drive for all window lengths

3.3.4 *Simplified Description of MATLAB Code*

An easier description for MATLAB code follows. For various variable names refer to Appendix A:

- Import the text file data in MATLAB by using either import wizard or textread command. Say data for Mud Pump is imported.
- Three vectors namely date, time and data are formed. As MATLAB plots the data VS index by default and index can be scaled to sample time we can delete the date and time vectors for simplicity. Plot the Mud Pump Flow VS Time (Figure 9).
- Vector mpdata is ready to use. A similar procedure is followed for pump pressure data to obtain and plot ppdata vector (Figure 10).

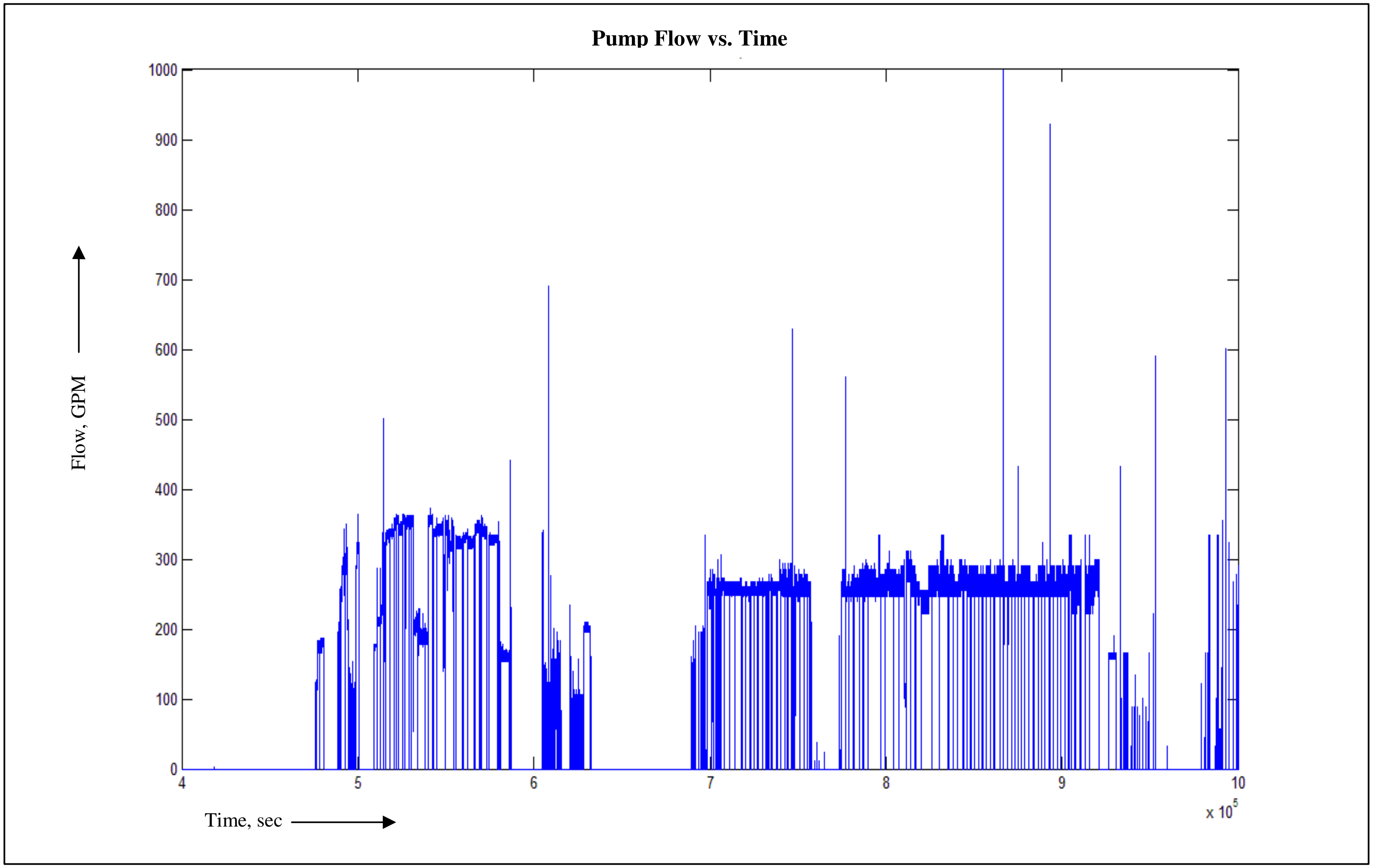

Figure 9 – Flow rate of one of the mud pumps and its variations with time.

- Point wise multiplication of pump pressure and mud pump flow will give the instantaneous power for the mud pump on time scale (Figure11).
- A moving average for a window length of 2 seconds is taken and plotted against this Mud Pump power curve. This is done because moving average is assumed to converge to the average value of a certain dataset and by increasing the window length the curve will move closer to base load value (Figure 12).
- Larger is the time period of moving average, greater will be the difference between original and moving average curve, lower will be the base load and larger will be the size of the flywheel.
- Rest of the peaks (difference between moving average and power) are plotted. The flywheel design is based on this difference between actual and moving average curve (Figure 13).
- A cumulative difference curve for Mud Pumps and Top Drive is plotted. This is the summary of all the peaks that flywheel unit will supply (Figure 14).
- An energy curve is obtained by adding all the previously consumed power peaks for both the mud pumps and top drive. This is done by adding all the n-1 values to the n^{th} value of peak and multiplying it by the time to give energy in KJ. This is done by using an inbuilt filter in MATLAB and can be found in the code given in the previous heading. All energy curves for the given window length are added.

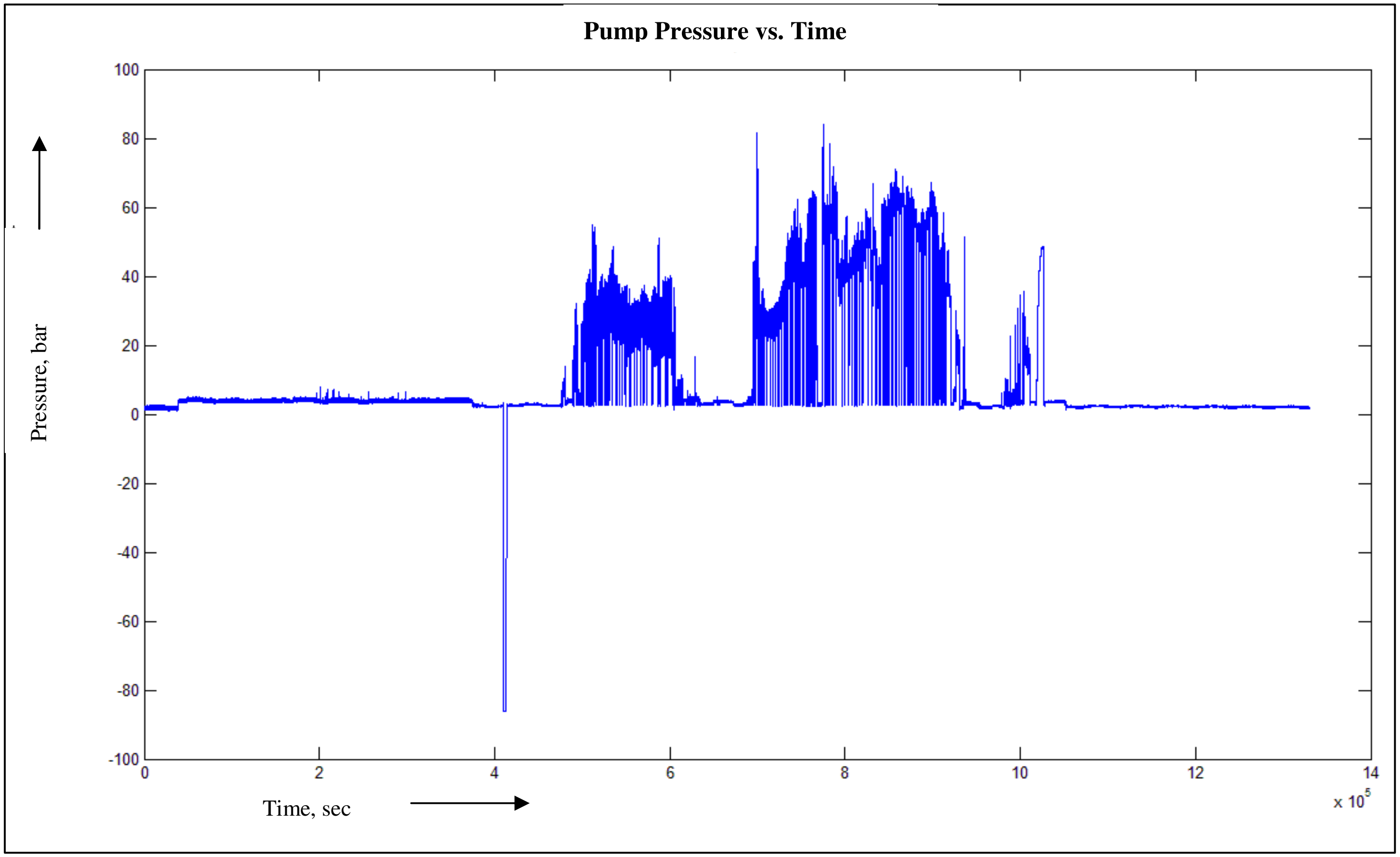

Figure 10 – Pump pressure vs. time is and its variations. Negative peak is considered to be a false triggered signal.

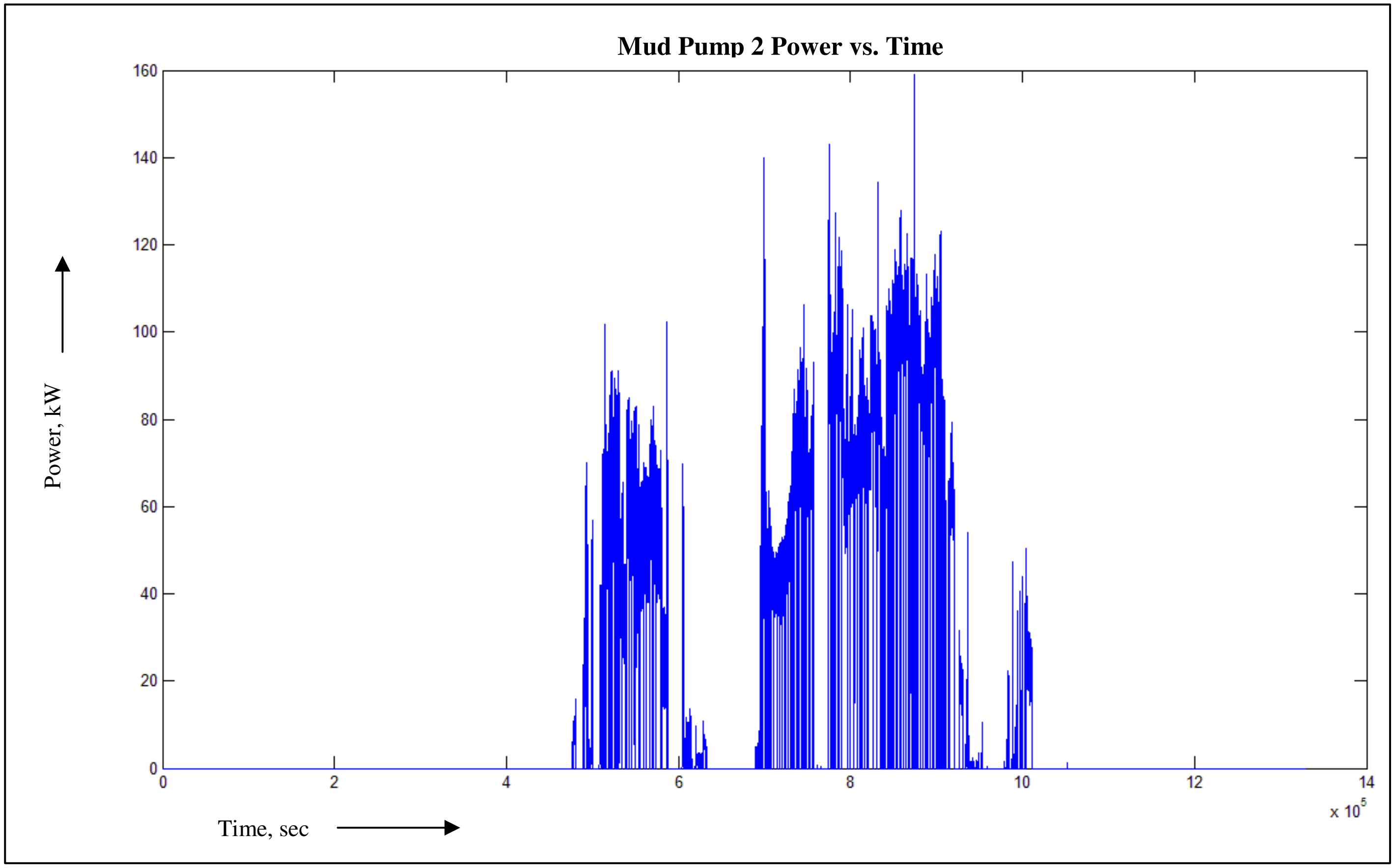

Figure 11 – Instantaneous power of mud pumps vs. time and its variations. Some of the exceptionally high values are considered to be false triggered.

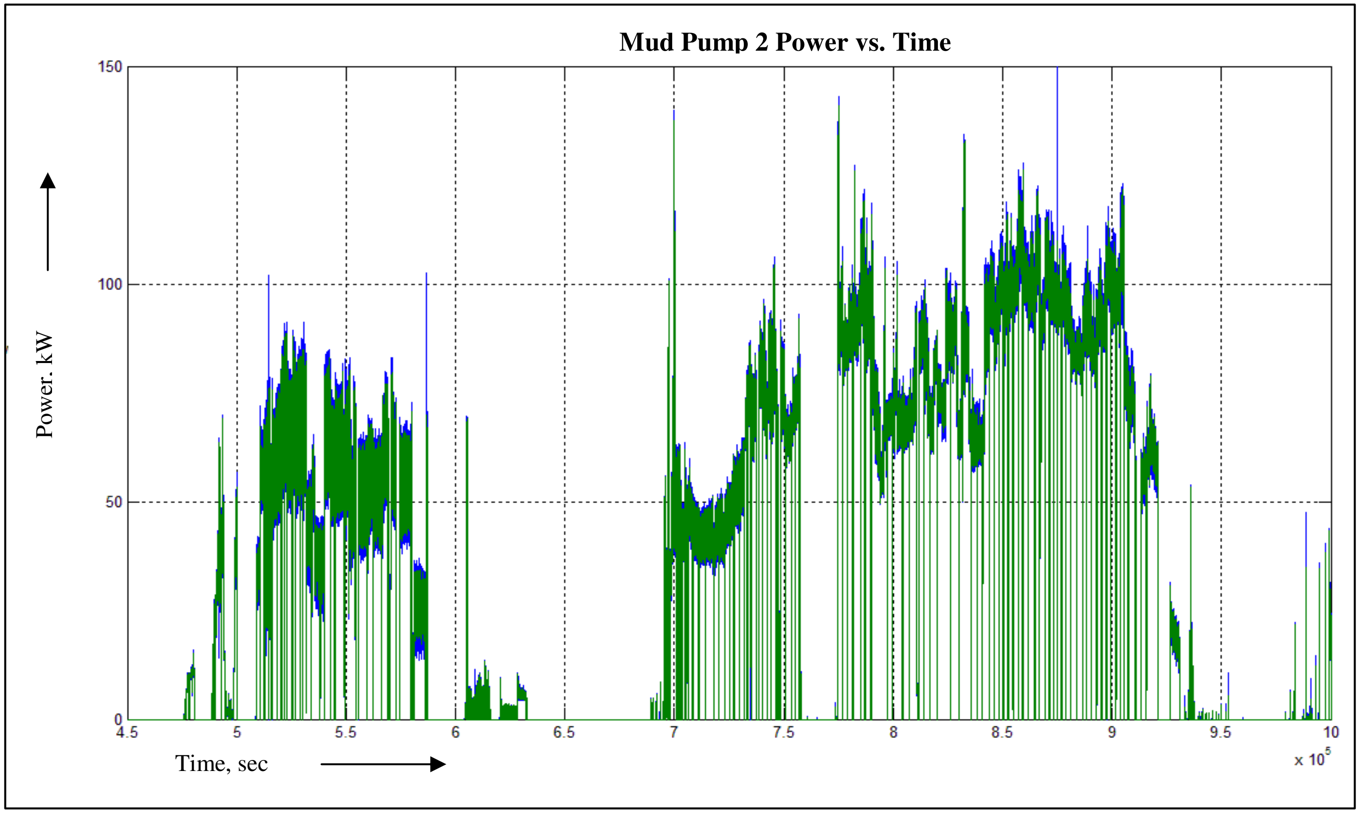

Figure 12 – A moving average of window length 2 seconds and actual power curve of the mud pump are plotted vs. time in order to determine transient peaks for this window length.

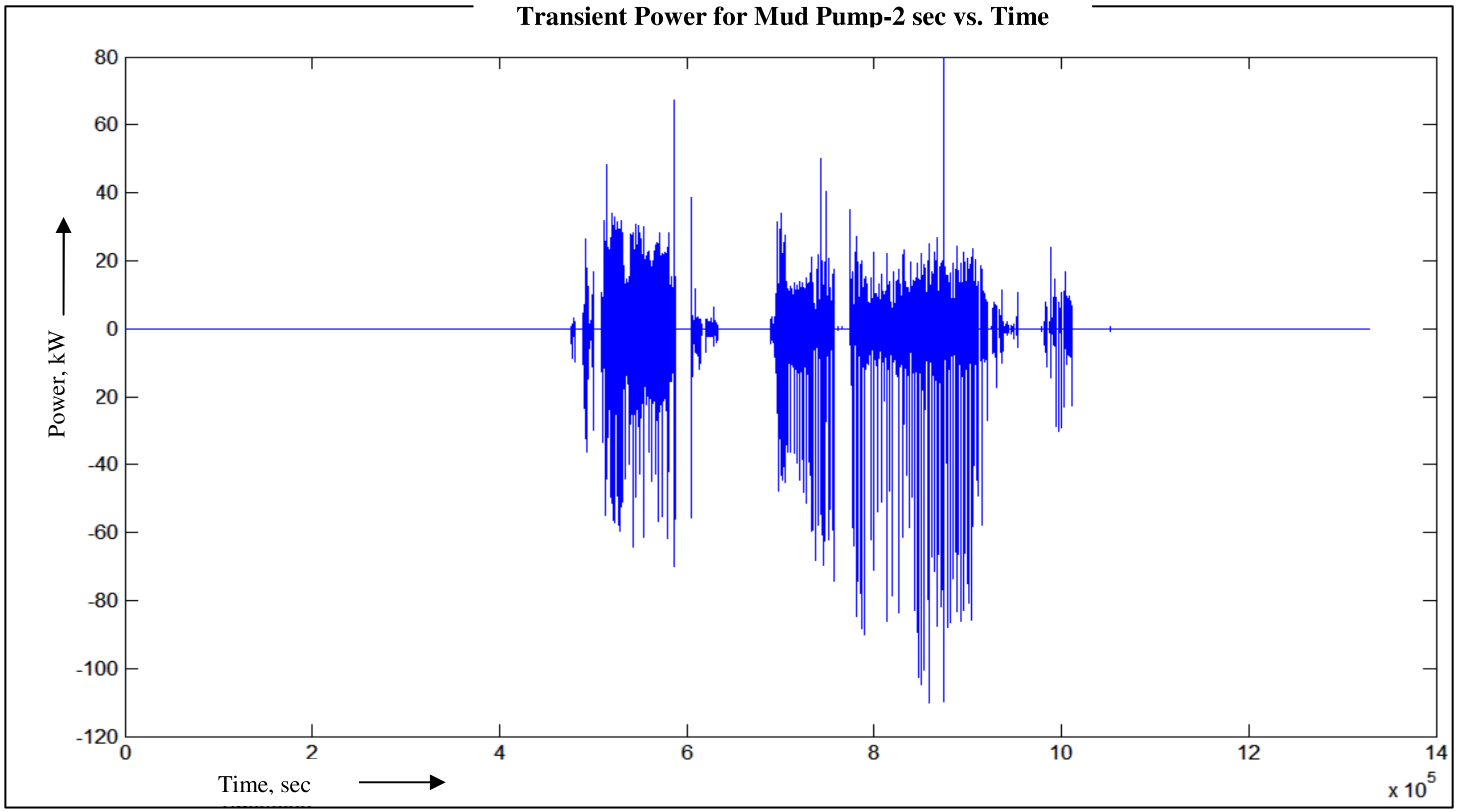

Figure 13 – Difference between the actual curve and moving average curve for the mud pump vs. time for the window length of 2 seconds.

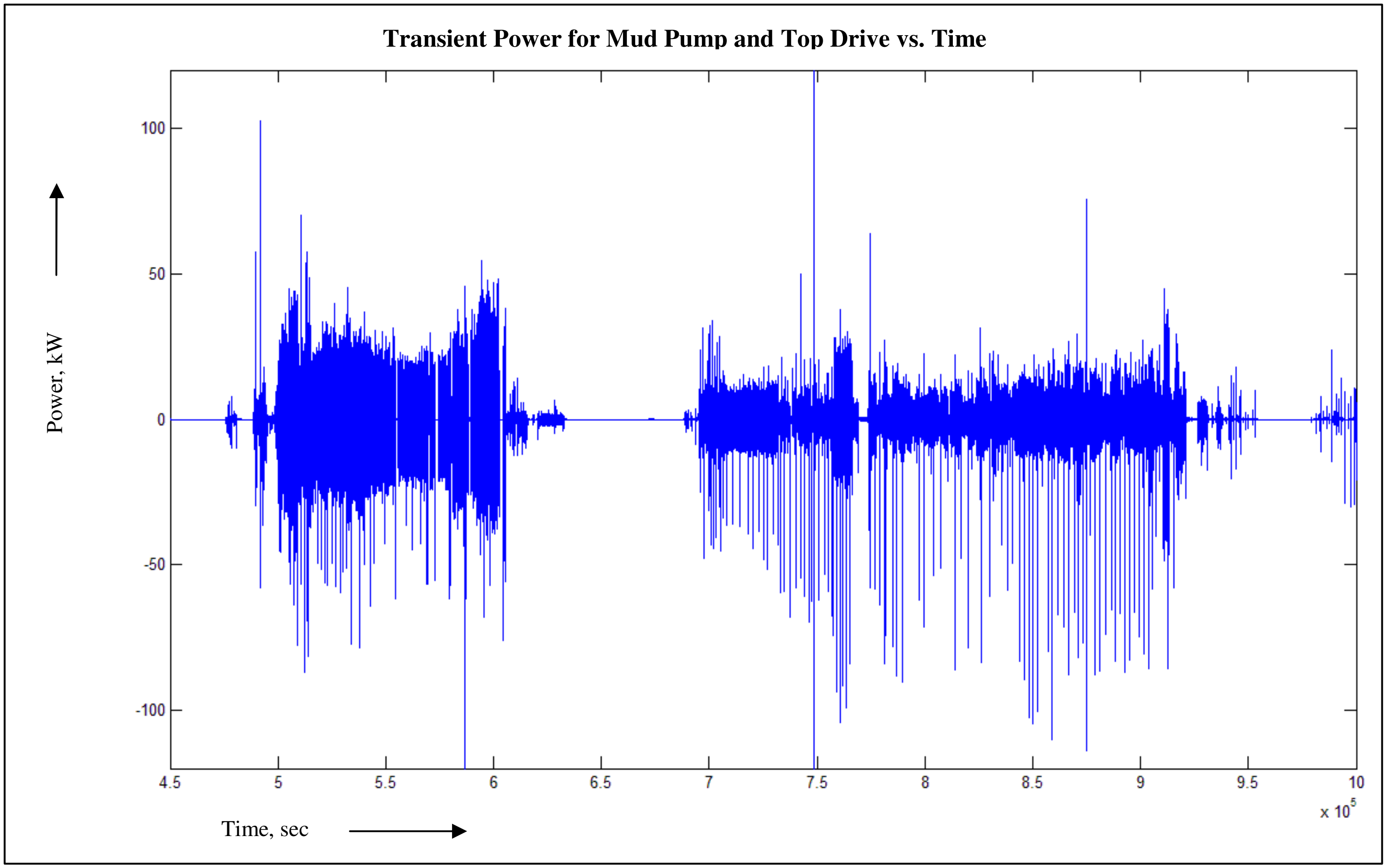

Figure 14 – Difference between the actual power curves and moving average curve combined for mud pumps and top drive vs. time.

- The peaks in this curve represents the minimum amount of energy flywheel unit should have for effective peak shaving. These energy curves are drawn for all window periods and are attached in the appendix. Hence after these eight steps we have the values for E_{max} and P_{max} for the flywheel unit.

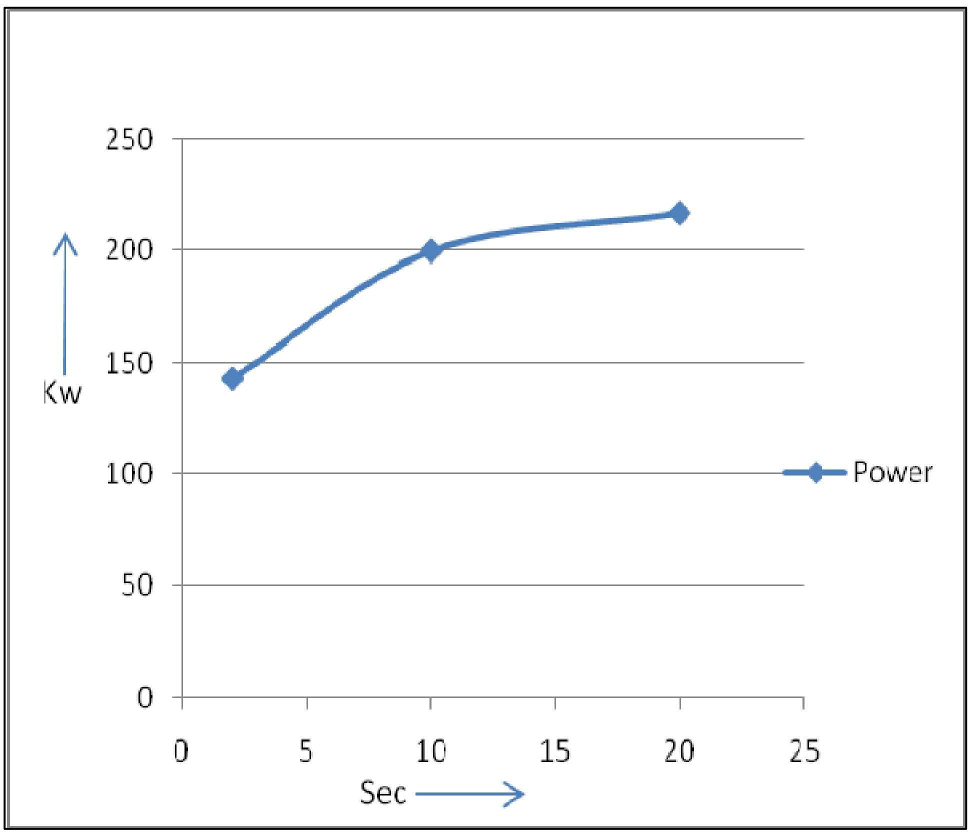

Figure 15 – Variation of KERS power requirement with window lengths.

Hence after a rigorous data processing we come up with the moving maximum power and maximum energy values which the flywheel unit has to provide in order to be effective for peak shaving. Figure 15 show variations of the value of power which increases with the increasing window length.

- The energy curve for mud pumps and top drive for window period of 2 seconds is shown (Figure 16).
- The energy consumption for both mud pumps and top drive is compared and shown in cumulative energy comparison graph. This graph proves that mud pumps are the largest energy consumers (Figure 17). This energy comparison is also done for all window lengths.
- Another curve of interest would be top drive power and depth on the same time scale which shows stages of drilling where top drive consumed power (Figure 18).
- Lastly power comparison with depth for mud pumps and top drive is made. These curves summarize the drilling operation. Drilling process started near to 9600000 second and halted at 12400000 second where there is no power consumption by any component. Again power consumption begins at 1400000 second and goes up to 1800000 second. The amount of power consumed individually by these pumps and top drive is also shown (Figure 19).

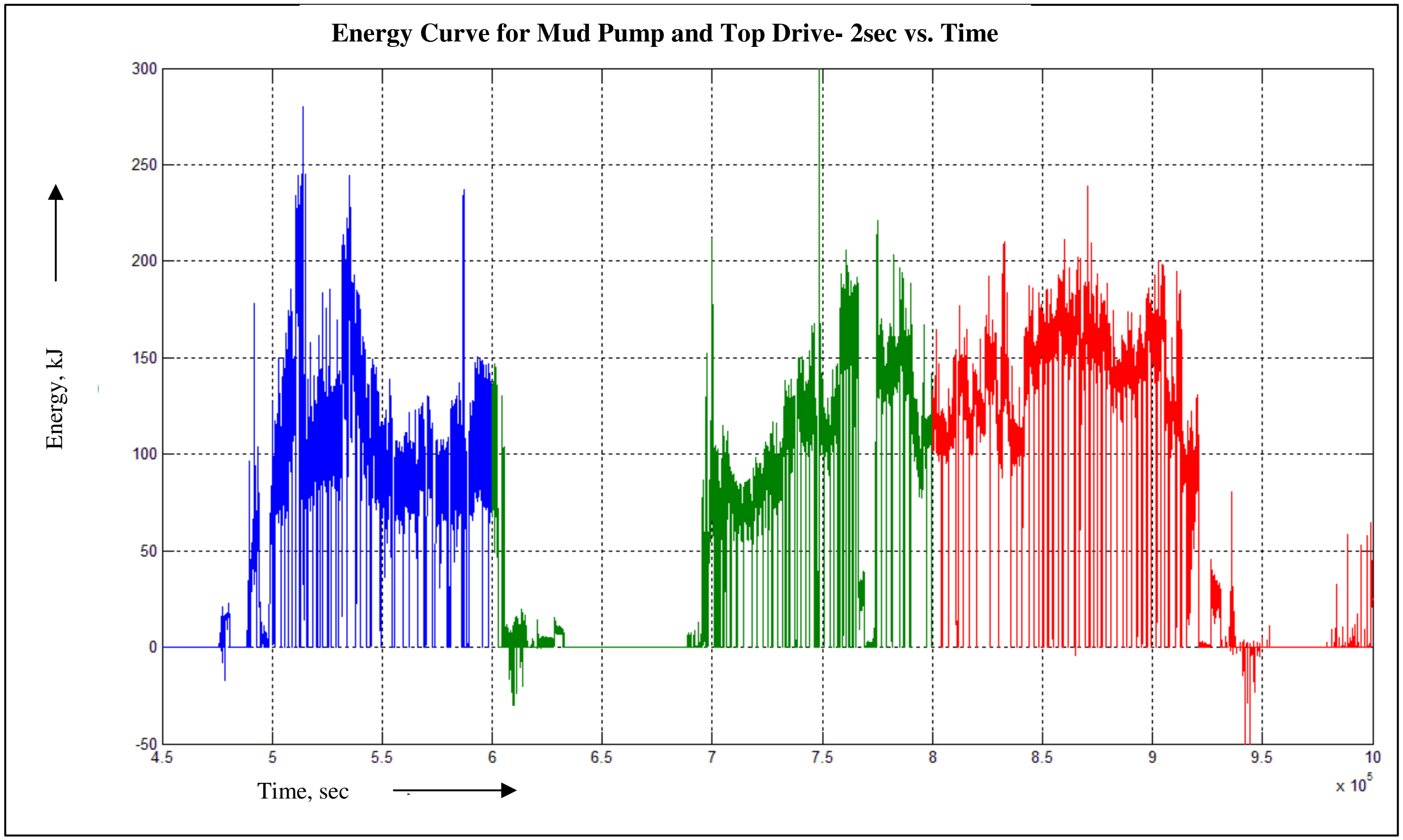

Figure 16- Energy curve for mud pumps and top drive for window length of 2 seconds.

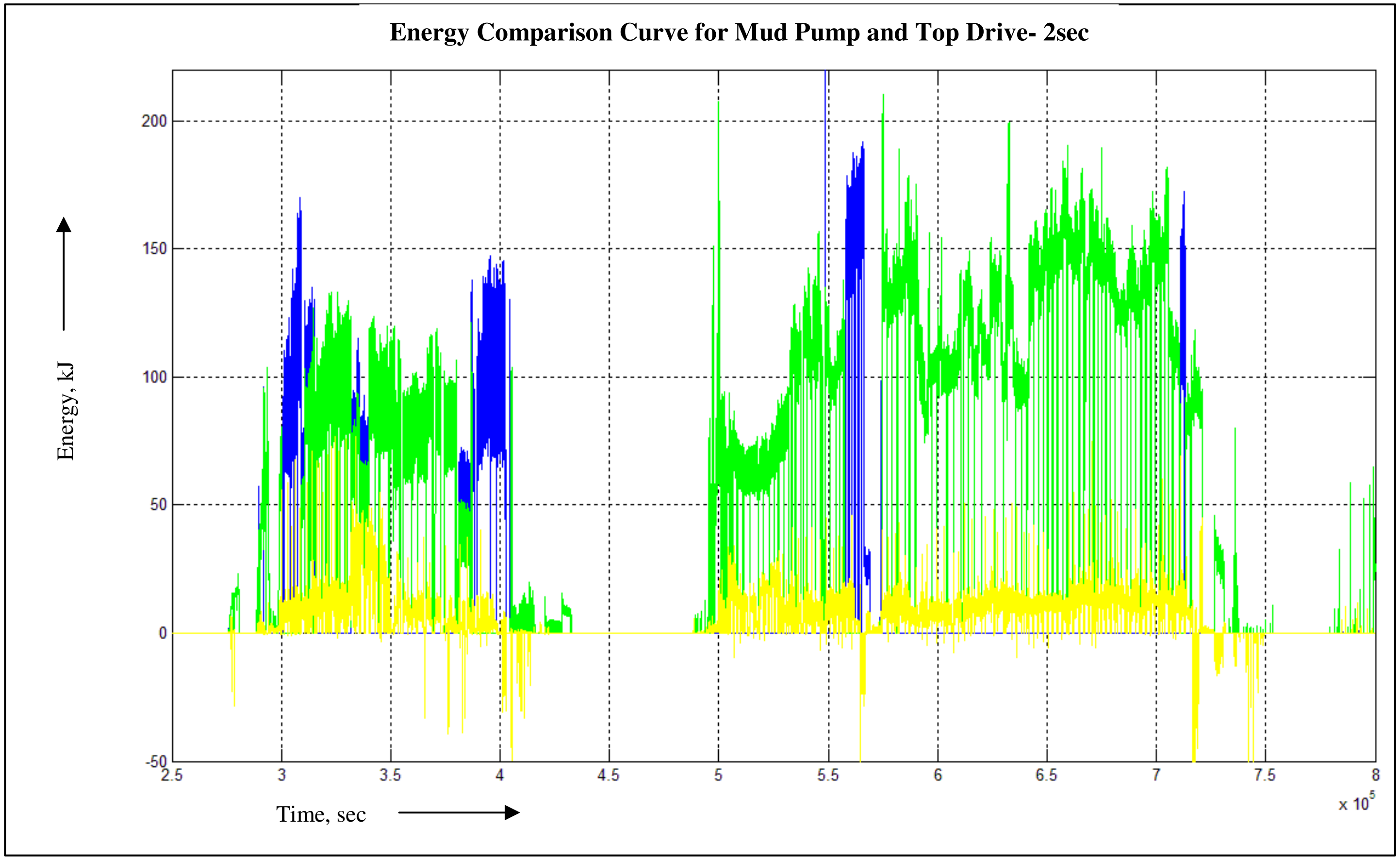

Figure 17 – Comparison of actual energy requirement of top drive and mud pumps vs. time and consumption of energy by mud pumps and top drive during drilling operation.

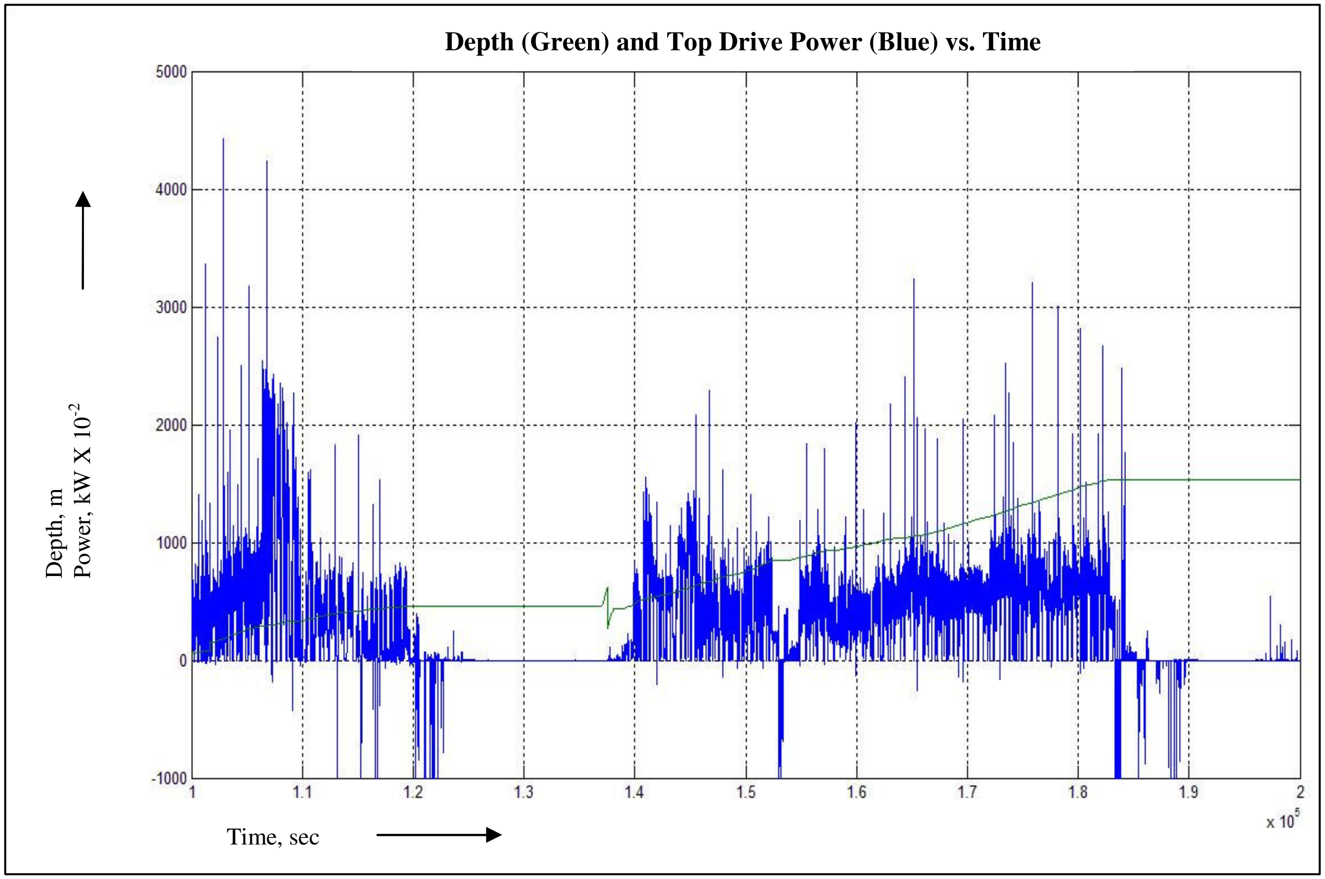

Figure 18 – Curve for drilling depth and simultaneous top drive power consumption vs. time.

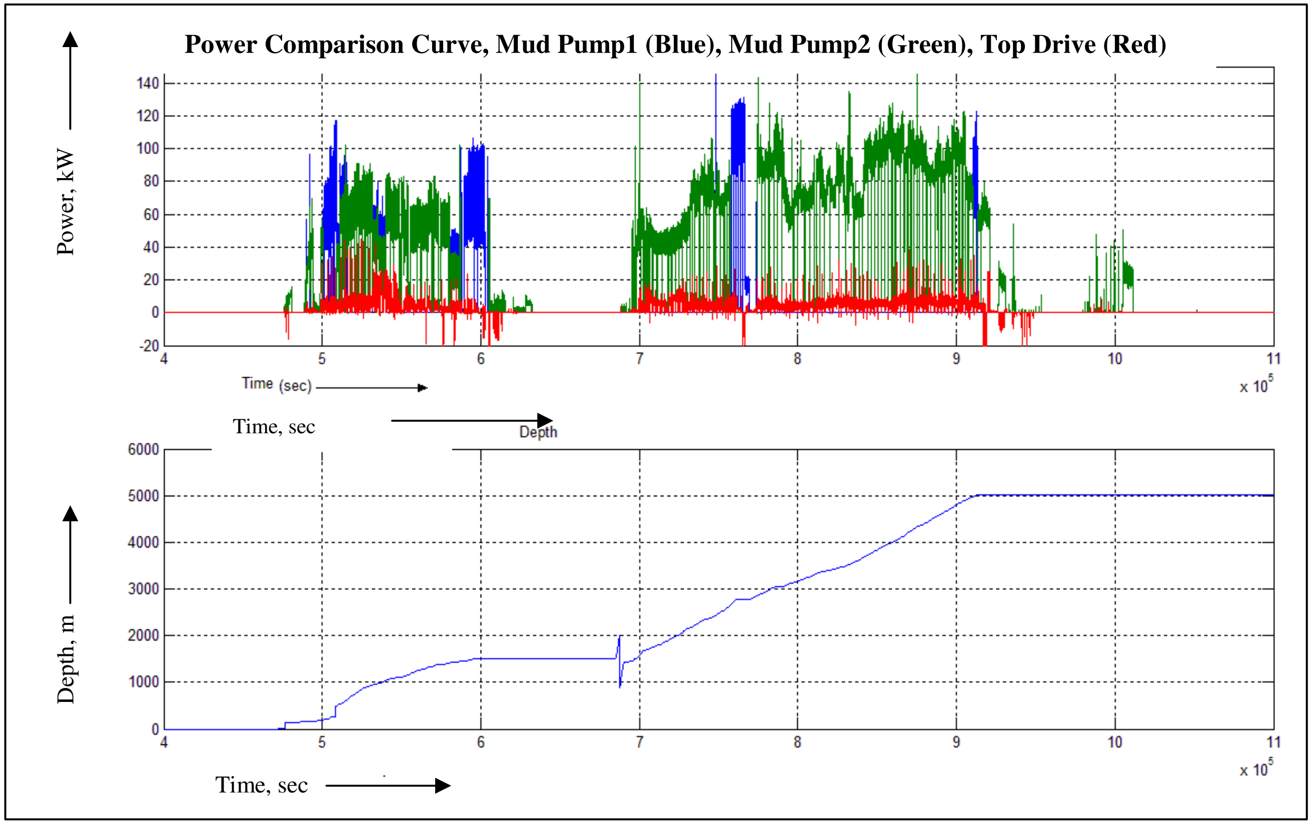

Figure 19 - Power consumption of mud pumps and top drive vs. time and variation with drilling depth.

3.3.5 Comparison of Theoretical and Actual Energy Audit

The following Table 6 shows a comparison between actual and theoretical energy audits conducted. Hence it is clear from these values that designing a system merely on the nameplate rating would have resulted in an overly designed system. Such a system would have been bulky and costly.

Table 6 - Comparison of actual and theoretical energy audit

Actuator	**(Hp)**	**(Hp)**
	Theoretical Values	**Actual Values**
Top Drive	103	57
Mud Pump1		215
Mud Pump2		213
Total Power for Mud Pumps	490	428

4. SYSTEM DESIGN BASED ON DATA PROCESSING

This section will illustrate the important components of alternate power system and their corresponding description. All of design mentioned here is based on the rig specification and data processing results.

4.1 Black Box Description

Initially the power system under design is assumed to be a black box. Following important points are considered before designing any component:

- Efficient Operation

  Design should be such that all kind of losses should be minimized. This includes T&D losses and all transformer losses.

- Reliable

  The possibility of total equipment breakdown should be negligible. Two transformers with a back up diesel generator add to the redundancy. Even if all the three fails the emergency rig up power can be used which itself can be operated from an energy storage device like flywheel or a super capacitor unit.

- Cost Effective

  In order for the system to be lucrative to operators, initial cost incurred should be minimal. With fluctuating gas prices, drilling with electricity can be economical. The goal will be to make this design much cheaper as compared to diesel fed rig.

- Safe Operation

Risk of shocks or accidents should be minimized. Huisman standards will be incorporated. Some of these measures include:

1. Equipment provided for protection of persons at work near electrical installations.
2. Equipment ability to bear electrical stresses and shocks.
3. Bus bar protection.
4. Protection from excess/short circuit current.
5. Cut off and isolation.
6. Working conditions, lighting, competent personal.
7. Protection against indirect contact.
8. Adequate earthing requirements.

- Mobile

  A mobile unit can reduce great deal of operator reluctance for transportation and set up. The switchbox dimensions will be decided so as to fit it in a 20 ft or 40 ft ISO standard container.

- Remote Operation

  The existing SCADA system on LOC 400 will be used to operate the transformer unit remotely and to monitor various predefined parameters.

A black box design is illustrated in Figure 19 considering all of the above factors. This diagram shows constituent components of the black box. A brief description of the black box design is also given following the diagram.

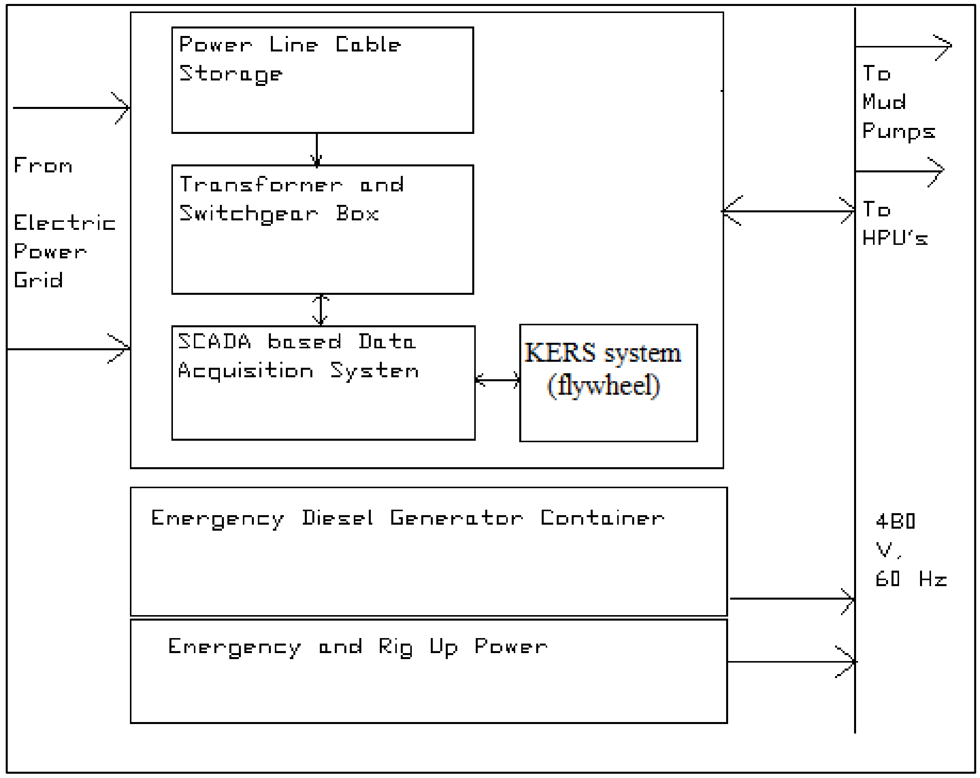

Figure 20 – Black box design for alternate power system.

The switchbox above contains many inbuilt blocks. One such block is dedicated transformer switchgear with feeder cables. Such a transformer station can be connected to a service voltage of 11 KV by a feeder cable which is another specially designed component. This 2 mile long feeder cable will be on a storage winch. The winch will have a close circuit coolant circulation in order to avoid overheating of the mounted cable while in operation. Another block would be the flywheel unit. Size, rating and specification of the flywheel unit are determined on the basis of rig data processing. There is one more data acquisition block which will monitor all the parameters while the unit is functional. Such a SCADA system is already in place in these rigs. After appropriate size determination all of these blocks will be placed in a 20 ft or 40 ft closed ISO container which has the inherent advantage of easy transportation with no special freight regulations. The overall system also contains emergency back up diesel generator unit in case the electrical design fails or power trips. A detailed design with dimensions will be shown later.

4.2 Component Description

4.2.1 Power Line Cable

Assuming an overall derating factor of 0.6 for ground (including air and ground temperatures, grouping of cables, depth of burial, overall derating factors for ground and air) (McAllister 1987) and calculating the transformer primary winding current for 3.3 MVA loading. The equation governing the primary current is given by:

I_p = 3300000/ (√3 X 11000) = 173.4 Amps…………………………..Equation 1

where I_p is the primary winding current.

Cable equivalent current for 25 ‘C = 173.4/0.6= 289.01 Amps………Equation 2

This value corresponds to a 3 core cable with cross sectional area of 95 mm^2 and outer core diameter of 12 mm in standard tables in the cable handbook (Fink and Beaty 1987).Thus the overall diameter of the cable would be 36 mm (Figure 13). This cable might be oil cooled from within. Environmental regulations governing laying this high voltage cable will be discussed later. Other details are-cable coding BS6622 95/100 mm^2, 37 wires for 600 V, PVC insulation, current rating of 3 core cable 11 KV XLPE insulation (McAllister 1987). Figure 20 shows a cross section of the power cable with the dimensions.

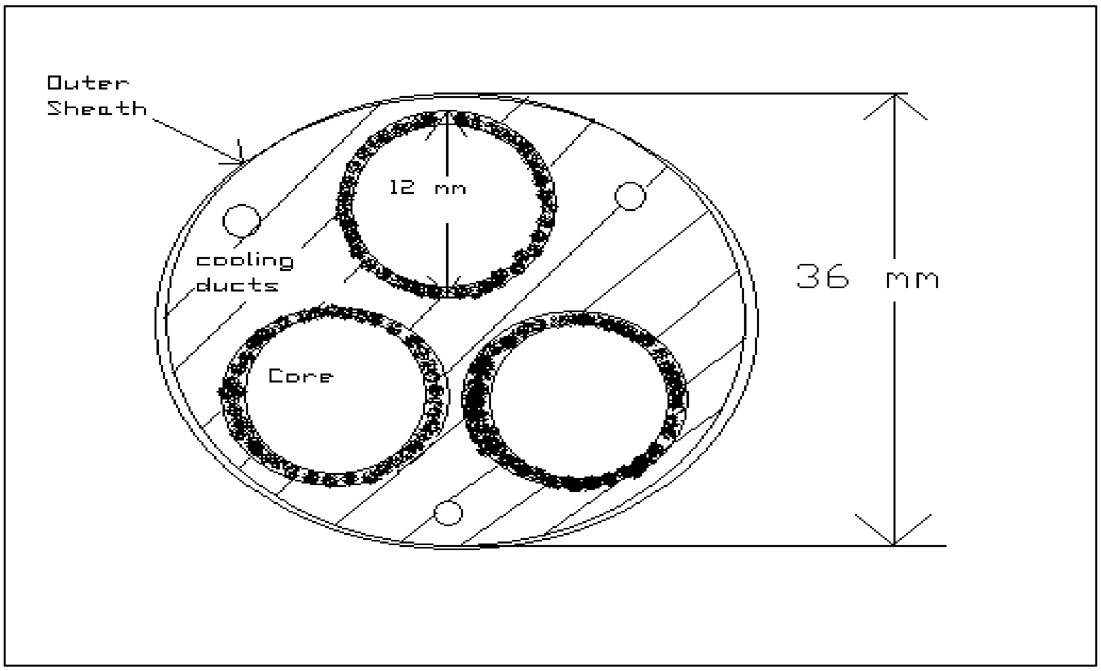

Figure 21 – Cross section of power cable with 3 inner cores and insulation.

4.2.2 Storage Winch

Storage winch in this system is used for holding as much as 3000 meters long power cable which can be used as an alternative to connect the rig to the power grid instead of constructing power lines to drill site. This winch has to be accommodated into 2.2 meter height and width dimension of ISO container. The winch's main design parameters are wire diameter 36 mm, drum wire storage 3042 m, number of safety windings 3, number of layers 16, drum diameter in groove 640 mm, length of the drum 2200 mm, ratio of wire/ drum diameter 17.78, pitch of the drum 37.44 mm.

4.2.3 Transformer and Switchgear

3 Phase, distribution type,11 KV/480 V,60 Hz, Class F,DZ. 2 transformers will be needed to replace either of the diesel engines. Incoming and bus bar section circuit breakers should be 3/4 pole for low voltage based on air break. For high voltage they should be either SF_6 or vacuum based. Earthing bars should be high grade copper located at front or rear enclosure, screen clamping type. Standard lightning arrestor and cabinet cooling system is also recommended (Alstom T&D Protection and Control 1995). Main bus bar is 400 amps, high grade copper (Westinghouse Electric Cooperation 1964). Control and indicators include power factor meter, voltmeter, ammeter, frequency meter, synchronising devices and varmeter. Fuses are in series with contactor with rating of 1.5~2 times normal load current. Standards for safety vary from designer to designer and the manufacturer. Detailed design is left up to the electrical design and installation company and superior quality equipment or equipment with industry wide standard usage is recommended.

4.2.4 SCADA System

Same as currently installed to measure all the drilling parameters. In addition a feature of measuring power and current usage and transient could be included for obtaining additional data sets.

4.2.5 KERS System

A high speed generator is coupled to the flywheel so as to attain maximum energy storage density. Magnetic bearing provides frictionless motion of the shaft. The entire unit is mounted in a vacuum enclosure to provide enhanced service life. Further a fully controlled inverter and a variable speed motor is connected which controls the charging and discharging of the unit. This arrangement is shown in Figure 21. A monitoring system is mounted on this for controlled operation (Kirby 2004). Flywheel in the current system is designed for recycling energy. It discharges energy when the load exceeds the prescribed limit. A commercially available flywheel system is considered to fit in the described system. Its ratings are- rated power 140 kW, duration 15 seconds, useable energy storage 2244 kW-sec max., flywheel rotational speed 36 to 24 KRPM, input voltage 420 - 600 VDC, recharge rate factory adjustable (per application) 12 minutes, typical stand by losses 2000 Watts, voltage discharge 400–500 VDC (adjustable per application), voltage regulation +/- 1%, DC ripple less than 2%, operating temperature -20 °C to 40 °C, humidity 95% non-condensing, altitude 1500 m max (without derating), audible noise 66 dBA at 1m, height 1981 mm, width 1219 mm, depth 610 mm, weight 872 kg (www.chloridepower.com). Table 6 summarize the results from data processing and explore the possibility of this flywheel unit for being successfully implemented in the overall system. Other modern high speed flywheel units can also be incorporated considering size constraint of 20 ft ISO container and safety regulations. This investigation is primarily concerned with proving that flywheel unit can be successfully implemented for peak shaving in drilling rigs.

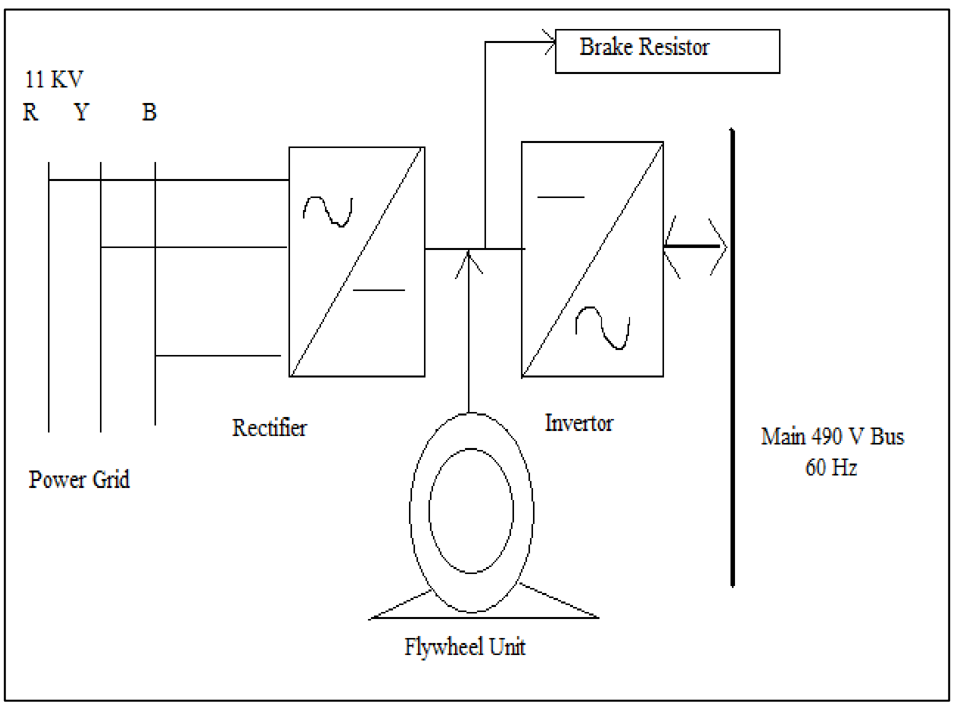

Figure 22 – KERS system positioning and operation

Table 7 – Data processing results and flywheel size determination

Window Length (sec)	*Maximum Energy (KJ)*	*KWh*	*Maximum Power (KW)*	*Flywheel height (cm)*	*Flywheel weight (Kg)*	*Cost ($/KW)*	*No. of Flywheels*	*Speed (Krpm)*
2	785	.2	143	198	872	300	1	24-36
10	28570	8	200	198	8720	300	10	24-36
20	122857	34	217	198	Not Feasible	300	Not feasible	24-36

Thus from Table 6 it is clear that a flywheel unit with the specifications mentioned can be successfully implemented for peak shaving up to 10 seconds. A comprehensive ISO container with all the components installed is shown in Figure 22. This is the concept phase design with basic details which shows feeder cables, transformer units and their cooling fans, switchgear, storage winch, winch cooling mechanism, AC unit, lighting unit. Intricate design of bus bars, circuit breaker and isolators, motor control centre cubicles and fuses are beyond the scope of investigation and are left up to the electrical design company.

Conceptual Design of Alternate Power System

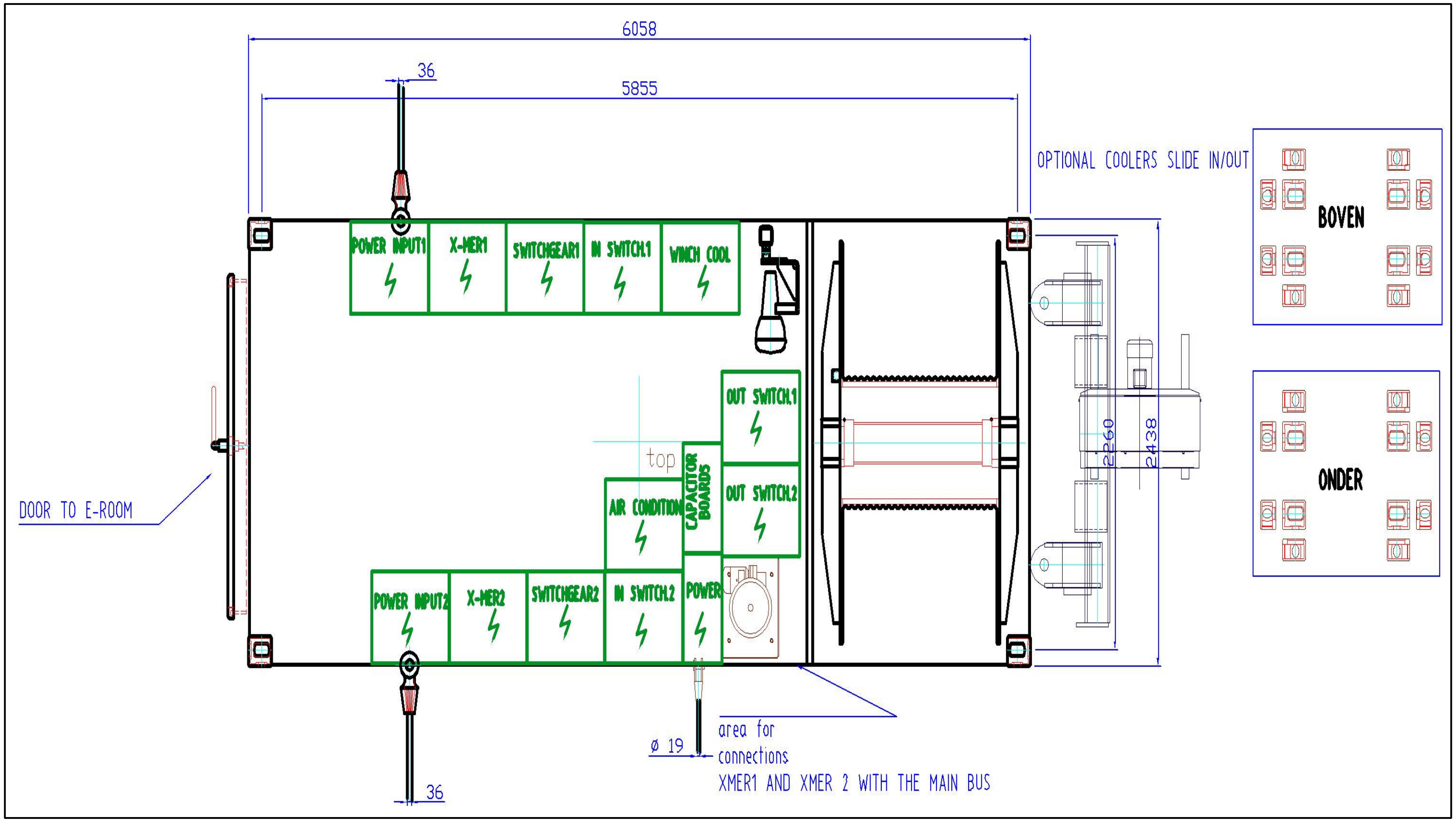

Figure 23 - Detailed design of alternate power system inside ISO container

5. CONCLUSION

5.1 Results

It is the operator who pays for diesel and its transportation. Hence electricity as an alternate energy source with peak shaving technology is lucrative in terms of return of investment and operational cost. In addition it is emission free and environmentally friendly technology. Table 8 exhibits a cost benefit analysis of grid drilling with peak shaving with conventional diesel drilling. Table 9 estimates various emissions during construction, transportation and usage of drilling equipment (Hendriks and Janzic, 2005). It also indicates that such emissions are much higher in case of conventional rigs as compared to the rig under consideration here. This system can eliminate the emissions during drilling and hence can play a crucial role in environmental protection.

Table 8- Cost benefit analysis of KERS system

Sr. No.	**Parameter**	**Diesel Operation**	**Electric Operation**
1	Consumption	3400 L/day or 870 Gal/day and 11920 Gal overall (Huisman 2006)	366769KWh@ 7cents/KWh and @ 80% of diesel fuel equivalent
2	Cost	**$28600**@ $2.4/Gal for 20 Days	**$26674** for 20 Days
3	Emissions	Noisy operation	Noise free operation (no moving parts like a generator)
4	Pollution and Environment	Emissions and pollutants (CO2,CO,NOx,SOx) due to transport and drilling	Environmentally friendly

Table 9 – Emissions data from construction, transport and usage of drilling equipment

		LOC-250	**Share (%)**	**Standard(low)**	**Share (%)**	**Standard(High)**	**Share (%)**
Weight	(t/well)	475		600		1000	
Transport							
CO_2	t/well	4	8	5	7	8	7
No_x	Kg/well	41	7	52	6	87	6
CO	Kg/well	8	5	10	4	17	4
PM	Kg/well	1	11	2	9	3	9
SO_2	Kg/well	5	65	7	65	11	65
Drilling							
CO_2	t/well	42	88	67	90	106	90
No_x	Kg/well	551	93	868	94	1374	94
CO	Kg/well	140	79	220	83	349	82
PM	Kg/well	12	89	19	91	29	91
SO_2	Kg/well	0	0	0	0	0	0
Construction							
CO_2	t/well	2	4	2	3	4	3
No_x	Kg/well	2	0	2	0	4	0
CO	Kg/well	29	16	36	14	60	14
PM	Kg/well	0	0	0	0	0	0
SO_2	Kg/well	3	35	4	35	6	35
Total			Relative to Standard(High)		Relative to Standard(High)		Standard(High)
CO_2	t/well	48	41	74	63	118	100
No_x	Kg/well	594	41	922	63	1465	100
CO	Kg/well	176	41	266	63	426	100
PM	Kg/well	13	41	20	63	32	100
SO_2	Kg/well	8	48	10	60	17	100

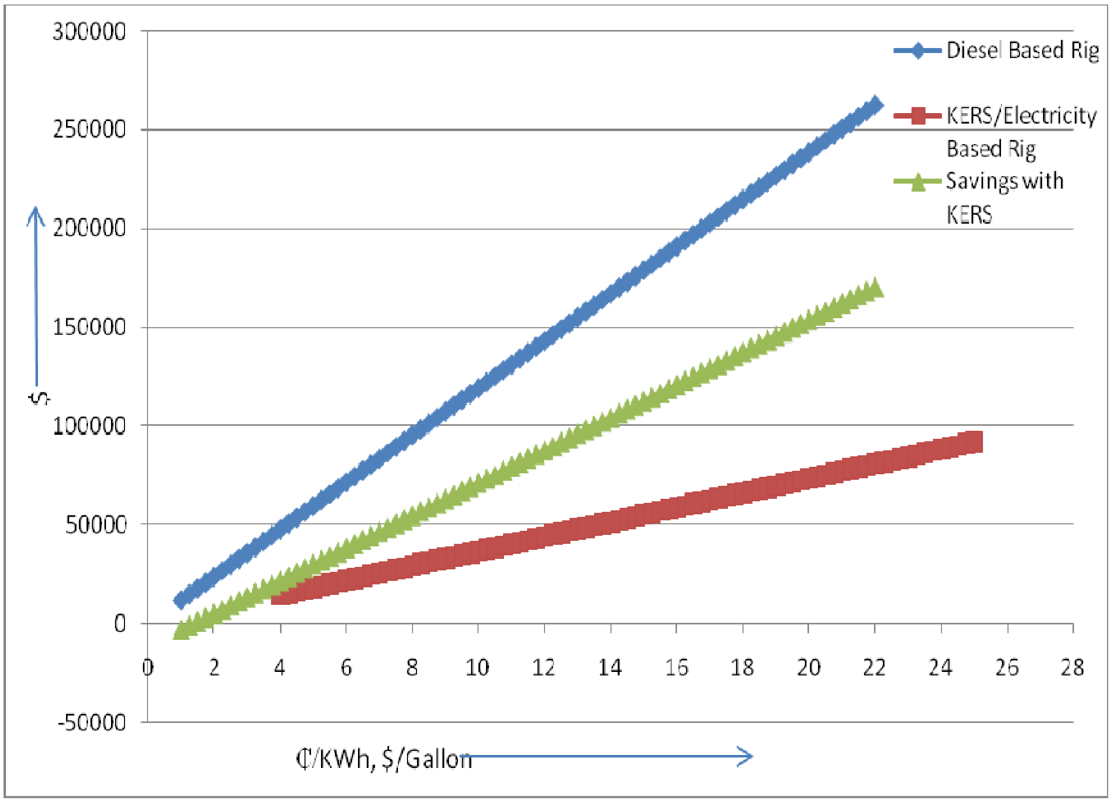

Figure 23 – Cost and savings curve for KERS system with diesel and electricity price variation

The cost benefit analysis in graphical format is shown in Figure 23. It is assumed that the prices of diesel and electricity will increase with time. The rate of increase might be different. The blue line is the trend of total cost per well with increasing diesel prices in $/Gallon. The brown trend line is the cost per well when KERS system described in this research is used. The green trend is savings while using KERS system at a particular diesel price per gallon. It is seen that when diesel prices were around a 1$/gallon use of the KERS system was not economic. Slowly increasing the diesel prices increases savings with alternate energy system as shown by the green trend line. Here it is assumed that the fuel consumption of a particular rig, LOC-250 in this case, will be more or less the same for an average well with average depth of 8000ft.

5.2 Inferences

Hence we come up with following conclusions from this research project:

- The power consumption of casing while drilling rigs, LOC-250 and LOC-400 is much lesser than conventional rigs.
- It is possible to connect these rigs to electrical grid. It is also possible to install a KERS system which can successfully provide peak shaving and reduce the transient power peaks.
- Such an alternate power system can be made mobile with no special freight requirements.
- LOC 400 being an electrically driven system can be easily connected to a power grid within 2 miles of radius.
- It is possible to eliminate all the drilling emissions with this KERS system operating with electrical grid.
- Savings after installing this system increase linearly with increasing cost of diesel.
- The rig with both alternate power system and conventional diesel engines consumes lesser diesel as compared to the same rig with standalone diesel engines. This is true for an average well duration of 20 days and average well depth of 8000 ft.

5.3 Future Work

Following investigation can also be conducted in future:

- Analysis of the regenerative power by LOC-400 and losses.
- Detailed design of switchgear and their single line diagrams with rating of fuses and circuit breakers.
- Replacement of flywheel by super capacitor units and redo the peak shaving design once super capacitors are successfully tested.
- Cost quotation and return of investment of switchgear components, flywheel unit, installation and maintenance.
- Design of cooling system for storage winch.
- Study of Environmental regulations in order to lay out high voltage cable on ground.
- Simulation of the circuit design.
- Safety guidelines for operation of KERS based rig power system.
- Interviews with utility companies regarding surcharges and special regulations which vary with state.
- Calculation of power factor of the rig.
- Lab testing of KERS coupled diesel engines to estimate exact fuel savings.

NOMENCLATURE

AC	Alternating Current
Amps	Amperes
˚C	Degree Centigrade
Cm	Centi Meters
CO_2	Carbon dioxide
DC	Direct Current
dBA	Decibels
ft	Feet
gpm	Gallons Per Minute
Hz	Hertz
ISO	International Organization of Standards
KERS	Kinetic Energy Recovery and Storage
kG	Kilo Grams
kJ	Kilo Joules
kRPM	Kilo Rotations Per Minute
kV	Kilo Volts
kW	Kilo Watts
kWh	Kilo Watt Hour
l	Litres
LOC 250	Land Offshore Containerized (with hook load of 250 Tonnes)

MATLAB	Mathematics Laboratory
mm	Milli Meter
MVA	Mega Electron Volt
NOx	Family of Nitrogen Oxides
SCADA	Supervisory Control And Data Acquisition System
SF_6	Sulphur Hexa Fluoride
SOx	Family of Sulphur Oxides
V	Volts
XLPE	Cross Linked Polyethylene

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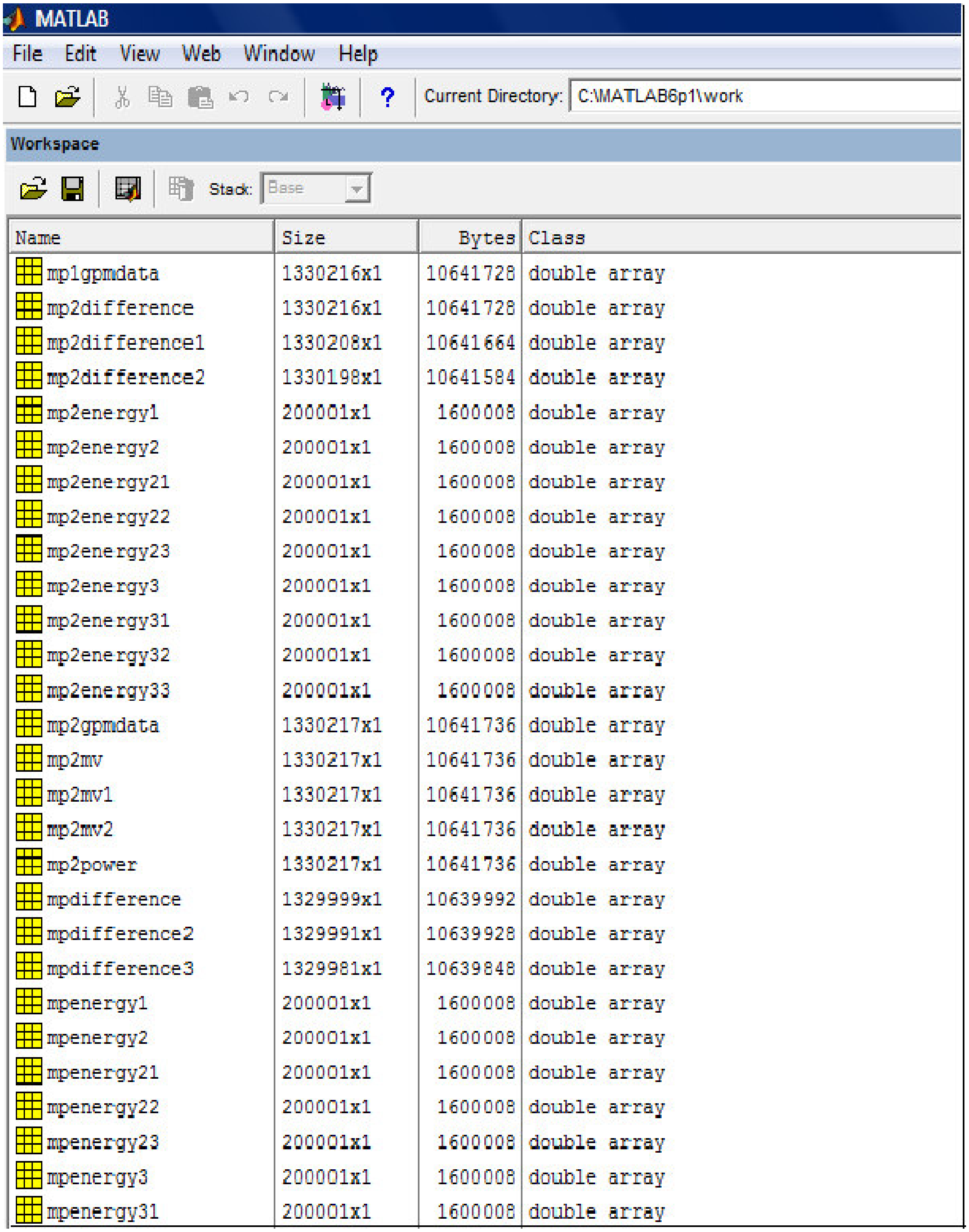
APPENDIX A

VARIABLE DESCRIPTION FOR MATLAB CODE AND SCREENSHOTS

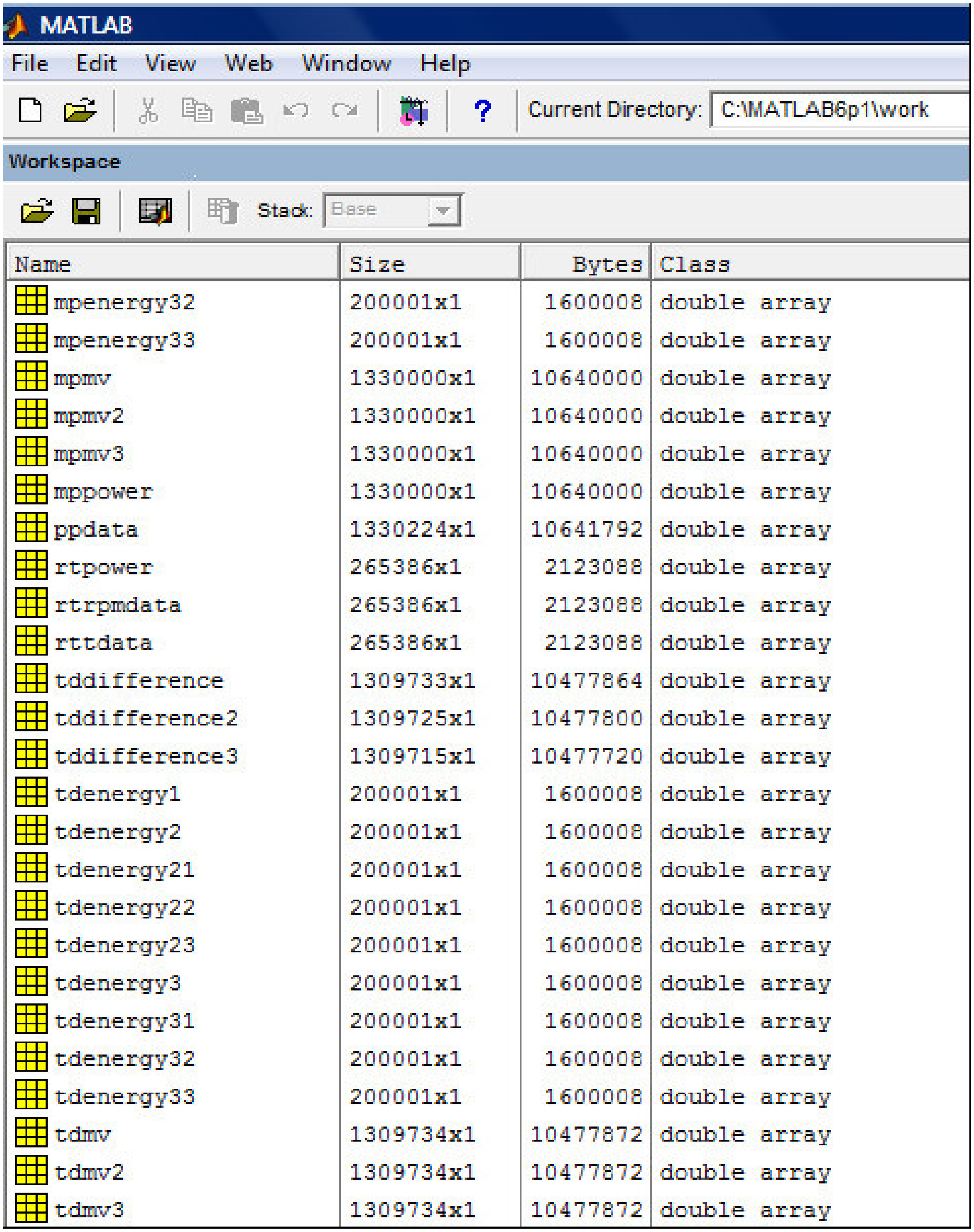
mp1gpmdata	Flow rate in GPM for mud pump 1
mppower	Power for mud pump 1(pump pressure X flow rate)
mpmv	Moving average of power for window length 2 Sec
mpmv2	Moving average of power for window length 10 Sec
mpmv3	Moving average of power for window length 20 Sec
mpdifference	Difference between mp1 power and 1st moving avg.
mpdifference2	Difference between mp1 power and 2nd moving avg.
mpdifference3	Difference between mp1 power and 3rd moving avg.
mpenergy1	Energy curve for 1st portion of first difference
mpenergy2	Energy curve for 2nd portion of first difference
mpenergy3	Energy curve for 3rd portion of first difference
mpenergy21	Energy curve for 1st portion of second difference
mpenergy22	Energy curve for 2nd portion of second difference
mpenergy23	Energy curve for 3rd portion of second difference
mpenergy31	Energy curve for 1st portion of third difference
mpenergy32	Energy curve for 2nd portion of third difference
mpenergy33	Energy curve for 3rd portion of third difference
mp2gpmdata	Flow rate in GPM for mud pump 1
mp2power	Power for mp1 (pump pressure X flow rate)
mp2mv	Moving average of mp2 power for window length 2 Sec
mp2mv2	Moving average of power for window length 10 Sec
mp2mv3	Moving average of power for window length 20 Sec

mp2difference	Difference between mp2 power and 1st moving avg.
mp2difference2	Difference between mp2 power and 2nd moving avg.
mp2difference3	Difference between mp2 power and 3rd moving avg.
mp2energy1	Energy curve for 1st portion of first difference
mp2energy2	Energy curve for 2nd portion of first difference
mp2energy3	Energy curve for 3rd portion of first difference
mp2energy21	Energy curve for 1st portion of second difference
mp2energy22	Energy curve for 2nd portion of second difference
mp2energy23	Energy curve for 3rd portion of second difference
mp2energy31	Energy curve for 1st portion of third difference
mp2energy32	Energy curve for 2nd portion of third difference
mp2energy33	Energy curve for 3rd portion of third difference
Ppdata	Pump pressure data
rttdata	Rotary table torque data
rtrpmdata	Rotary table RPM data
rtpower	Rotary table power data
tdtdata	Top drive torque data
tdrpmdata	Top drive RPM data
tdpower	Rotary table power data
tdmv	Moving average of tdpower for Window Length 2 Sec
tdmv2	Moving average of tdpower for Window Length 10 Sec
tdmv3	Moving average of tdpower for Window Length 20 Sec

tddifference	Difference between td power and 1st moving avg.
tddifference2	Difference between td power and 2nd moving avg.
tddifference3	Difference between td power and 3rd moving avg.
tdenergy1	Energy curve for 1st portion of first difference
tdenergy2	Energy curve for 2nd portion of first difference
tdenergy3	Energy curve for 3rd portion of first difference
tdenergy21	Energy curve for 1st portion of second difference
tdenergy22	Energy curve for 2nd portion of second difference
tdenergy23	Energy curve for 3rd portion of second difference
tdenergy31	Energy curve for 1st portion of third difference
tdenergy32	Energy curve for 2nd portion of third difference
tdenergy33	Energy curve for 3rd portion of third difference
z	a 1330000 X 1 vector (used for multiple plots)



Name	Size	Bytes	Class
mp1gpmdata	1330216x1	10641728	double array
mp2difference	1330216x1	10641728	double array
mp2difference1	1330208x1	10641664	double array
mp2difference2	1330198x1	10641584	double array
mp2energy1	200001x1	1600008	double array
mp2energy2	200001x1	1600008	double array
mp2energy21	200001x1	1600008	double array
mp2energy22	200001x1	1600008	double array
mp2energy23	200001x1	1600008	double array
mp2energy3	200001x1	1600008	double array
mp2energy31	200001x1	1600008	double array
mp2energy32	200001x1	1600008	double array
mp2energy33	200001x1	1600008	double array
mp2gpmdata	1330217x1	10641736	double array
mp2mv	1330217x1	10641736	double array
mp2mv1	1330217x1	10641736	double array
mp2mv2	1330217x1	10641736	double array
mp2power	1330217x1	10641736	double array
mpdifference	1329999x1	10639992	double array
mpdifference2	1329991x1	10639928	double array
mpdifference3	1329981x1	10639848	double array
mpenergy1	200001x1	1600008	double array
mpenergy2	200001x1	1600008	double array
mpenergy21	200001x1	1600008	double array
mpenergy22	200001x1	1600008	double array
mpenergy23	200001x1	1600008	double array
mpenergy3	200001x1	1600008	double array
mpenergy31	200001x1	1600008	double array



Name	Size	Bytes	Class
mpenergy32	200001x1	1600008	double array
mpenergy33	200001x1	1600008	double array
mpmv	1330000x1	10640000	double array
mpmv2	1330000x1	10640000	double array
mpmv3	1330000x1	10640000	double array
mppower	1330000x1	10640000	double array
ppdata	1330224x1	10641792	double array
rtpower	265386x1	2123088	double array
rtrpmdata	265386x1	2123088	double array
rttdata	265386x1	2123088	double array
tddifference	1309733x1	10477864	double array
tddifference2	1309725x1	10477800	double array
tddifference3	1309715x1	10477720	double array
tdenergy1	200001x1	1600008	double array
tdenergy2	200001x1	1600008	double array
tdenergy21	200001x1	1600008	double array
tdenergy22	200001x1	1600008	double array
tdenergy23	200001x1	1600008	double array
tdenergy3	200001x1	1600008	double array
tdenergy31	200001x1	1600008	double array
tdenergy32	200001x1	1600008	double array
tdenergy33	200001x1	1600008	double array
tdmv	1309734x1	10477872	double array
tdmv2	1309734x1	10477872	double array
tdmv3	1309734x1	10477872	double array

APPENDIX B

CONVERSION FACTORS

Unit conversion so that Y axis is in terms of power in kW.

For mud pumps:

1 gallon (US) =.00378 m^3

1 bar=10^5 N/m^2

Therefore GPM x Pump Pressure (bar) = .00378 m^3 /60x 10^5 N/m^2 = **.0063** kW

……………..Equation A1

For top drive and rotary table:

Power= Torque (N-m) x RPM/60 =2 x 3.14/60 =.1046 Watts/1000=**1.0046 x 10^{-4}** kW

…………….Equation A2

An efficiency factor of 0.7 is also multiplied by the amount of maximum power and maximum energy estimated to be supplied from KERS system on the basis of data processing.

Unit Conversion so that X axis is in terms of time in seconds.

For mud pumps each division on X axis represents 2 seconds which is the sampling frequency from Table A-3.

For top drive each division on X axis represents 2 seconds which is the sampling frequency from Table A-3.

APPENDIX C

RESULTS DATA

Commercial Electricity Rates,₵/KWh	**Diesel Rates in $/Gal**	**Total Diesel cost for a 20 Day well,$**	**Total Electricity cost for 20 day well,$**	**Savings/Well,$**
4	1	11920	14670.76	-2750.76
4.25	1.25	14900	15587.6825	-687.6825
4.5	1.5	17880	16504.605	1375.395
4.75	1.75	20860	17421.5275	3438.4725
5	2	23840	18338.45	5501.55
5.25	2.25	26820	19255.3725	7564.6275
5.5	2.5	29800	20172.295	9627.705
5.75	2.75	32780	21089.2175	11690.7825
6	3	35760	22006.14	13753.86
6.25	3.25	38740	22923.0625	15816.9375
6.5	3.5	41720	23839.985	17880.015
6.75	3.75	44700	24756.9075	19943.0925
7	4	47680	25673.83	22006.17
7.25	4.25	50660	26590.7525	24069.2475
7.5	4.5	53640	27507.675	26132.325
7.75	4.75	56620	28424.5975	28195.4025
8	5	59600	29341.52	30258.48
8.25	5.25	62580	30258.4425	32321.5575
8.5	5.5	65560	31175.365	34384.635
8.75	5.75	68540	32092.2875	36447.7125
9	6	71520	33009.21	38510.79
9.25	6.25	74500	33926.1325	40573.8675
9.5	6.5	77480	34843.055	42636.945
9.75	6.75	80460	35759.9775	44700.0225
10	7	83440	36676.9	46763.1
10.25	7.25	86420	37593.8225	48826.1775
10.5	7.5	89400	38510.745	50889.255
10.75	7.75	92380	39427.6675	52952.3325
11	8	95360	40344.59	55015.41
11.25	8.25	98340	41261.5125	57078.4875
11.5	8.5	101320	42178.435	59141.565
11.75	8.75	104300	43095.3575	61204.6425
12	9	107280	44012.28	63267.72
12.25	9.25	110260	44929.2025	65330.7975
12.75	9.75	116220	46763.0475	69456.9525
13	10	119200	47679.97	71520.03
13.25	10.25	122180	48596.8925	73583.1075
13.5	10.5	125160	49513.815	75646.185

Commercial Electricity Rates,₵/KWh	**Diesel Rates in $/Gal**	**Total Diesel cost for a 20 Day well,$**	**Total Electricity cost for 20 day well,$**	**Savings/Well,$**
13.75	10.75	128140	50430.7375	77709.2625
14	11	131120	51347.66	79772.34
14.25	11.25	134100	52264.5825	81835.4175
14.5	11.5	137080	53181.505	83898.495
14.75	11.75	140060	54098.4275	85961.5725
15	12	143040	55015.35	88024.65
15.25	12.25	146020	55932.2725	90087.7275
15.5	12.5	149000	56849.195	92150.805
15.75	12.75	151980	57766.1175	94213.8825
16	13	154960	58683.04	96276.96
16.25	13.25	157940	59599.9625	98340.0375
16.5	13.5	160920	60516.885	100403.115
16.75	13.75	163900	61433.8075	102466.1925
17	14	166880	62350.73	104529.27
17.25	14.25	169860	63267.6525	106592.3475
17.5	14.5	172840	64184.575	108655.425
17.75	14.75	175820	65101.4975	110718.5025
18	15	178800	66018.42	112781.58
18.25	15.25	181780	66935.3425	114844.6575
18.5	15.5	184760	67852.265	116907.735
18.75	15.75	187740	68769.1875	118970.8125
19	16	190720	69686.11	121033.89
19.25	16.25	193700	70603.0325	123096.9675
19.5	16.5	196680	71519.955	125160.045
19.75	16.75	199660	72436.8775	127223.1225
20	17	202640	73353.8	129286.2
20.25	17.25	205620	74270.7225	131349.2775
20.5	17.5	208600	75187.645	133412.355
20.75	17.75	211580	76104.5675	135475.4325
21	18	214560	77021.49	137538.51
21.25	18.25	217540	77938.4125	139601.5875
21.5	18.5	220520	78855.335	141664.665
21.75	18.75	223500	79772.2575	143727.7425
22.25	19.25	229460	81606.1025	147853.8975
22.5	19.5	232440	82523.025	149916.975
22.75	19.75	235420	83439.9475	151980.0525
23	20	238400	84356.87	154043.13
23.25	20.25	241380	85273.7925	156106.2075

Commercial Electricity Rates,₡/KWh	Diesel Rates in $/Gal	Total Diesel cost for a 20 Day well,$	Total Electricity cost for 20 day well,$	Savings/Well,$
23.5	20.5	244360	86190.715	158169.285
23.75	20.75	247340	87107.6375	160232.3625
24	21	250320	88024.56	162295.44
24.25	21.25	253300	88941.4825	164358.5175
24.5	21.5	256280	89858.405	166421.595
24.75	21.75	259260	90775.3275	168484.6725
25	22	262240	91692.25	170547.75

APPENDIX D

OTHER IMPORTANT MATLAB PLOTS

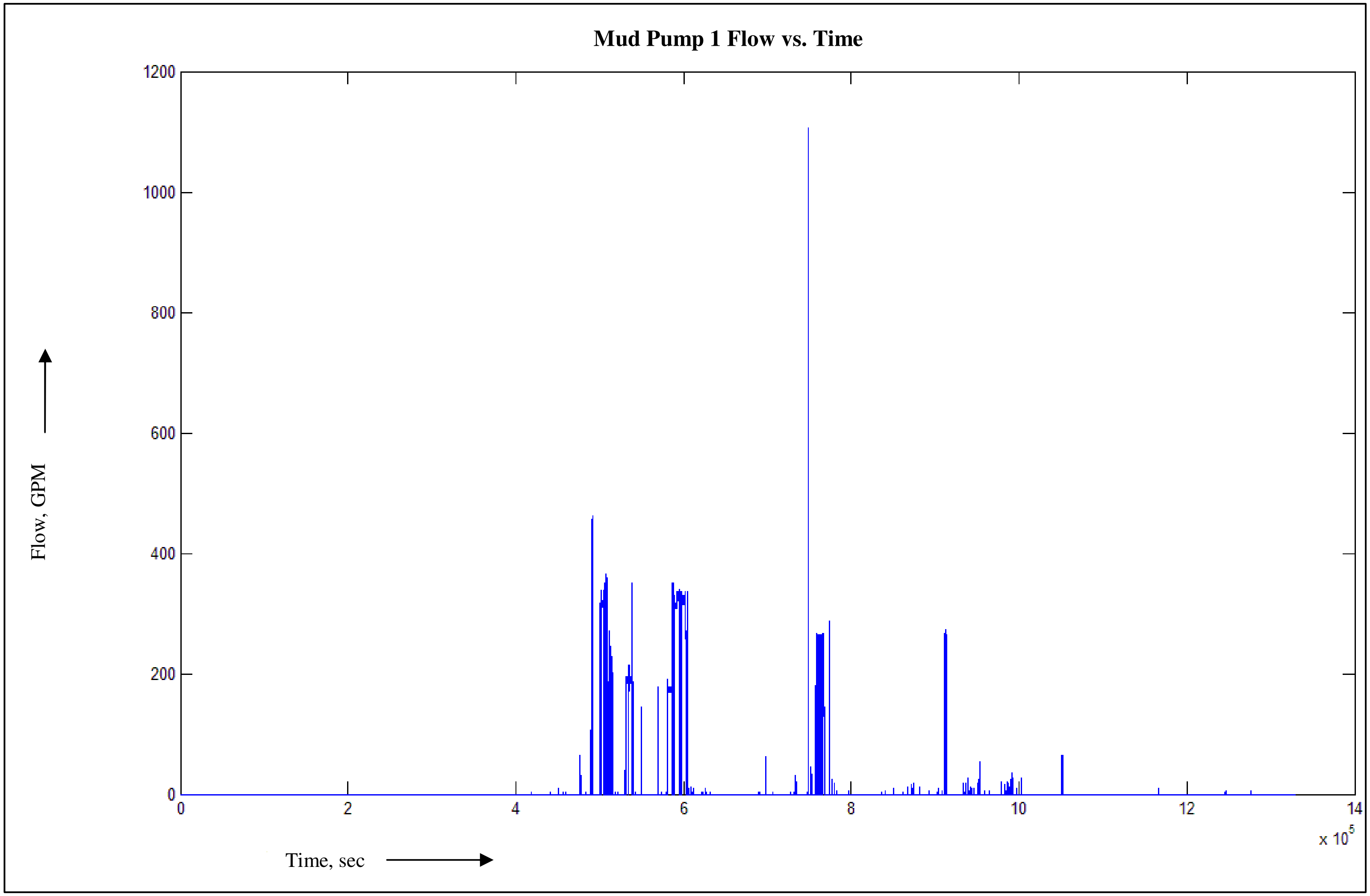


Figure A1 - Mud Pump 1 flow rate

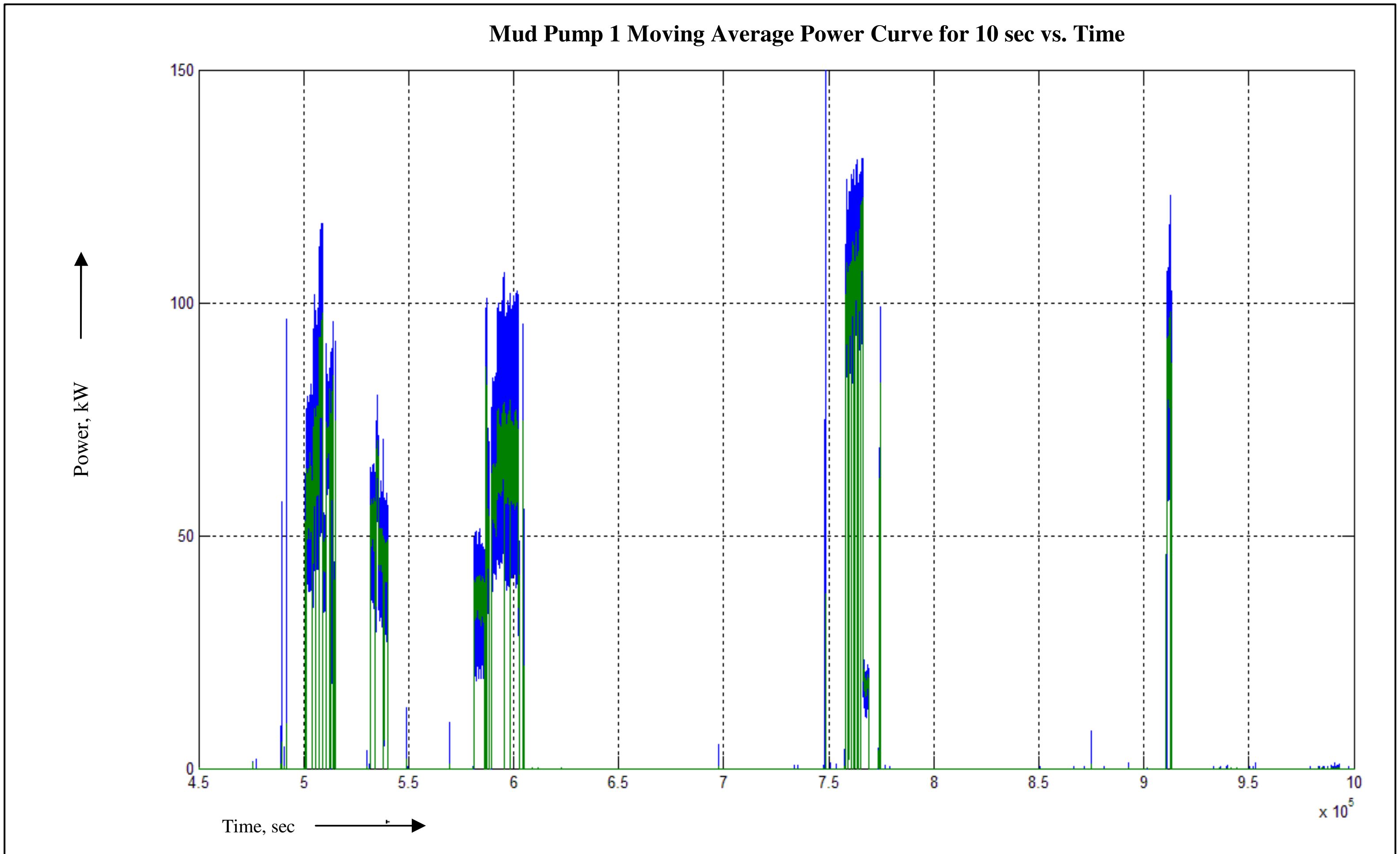


Figure A2 - Mud Pump 1 instantaneous power (blue) and moving average (green) of window length of 10 seconds

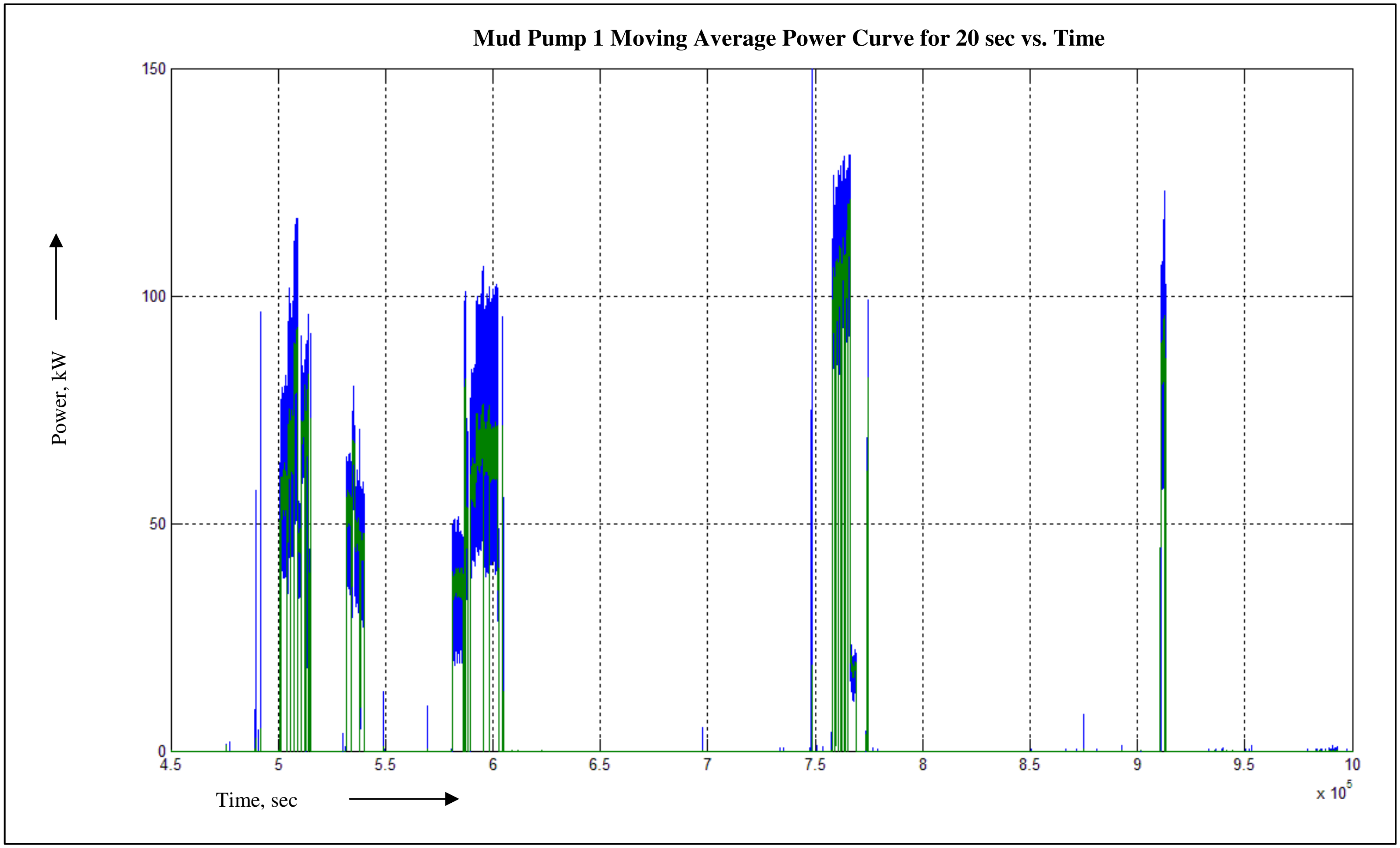


Figure A3 - Mud Pump 1 instantaneous power (blue) and moving average (green) of window length 20 seconds

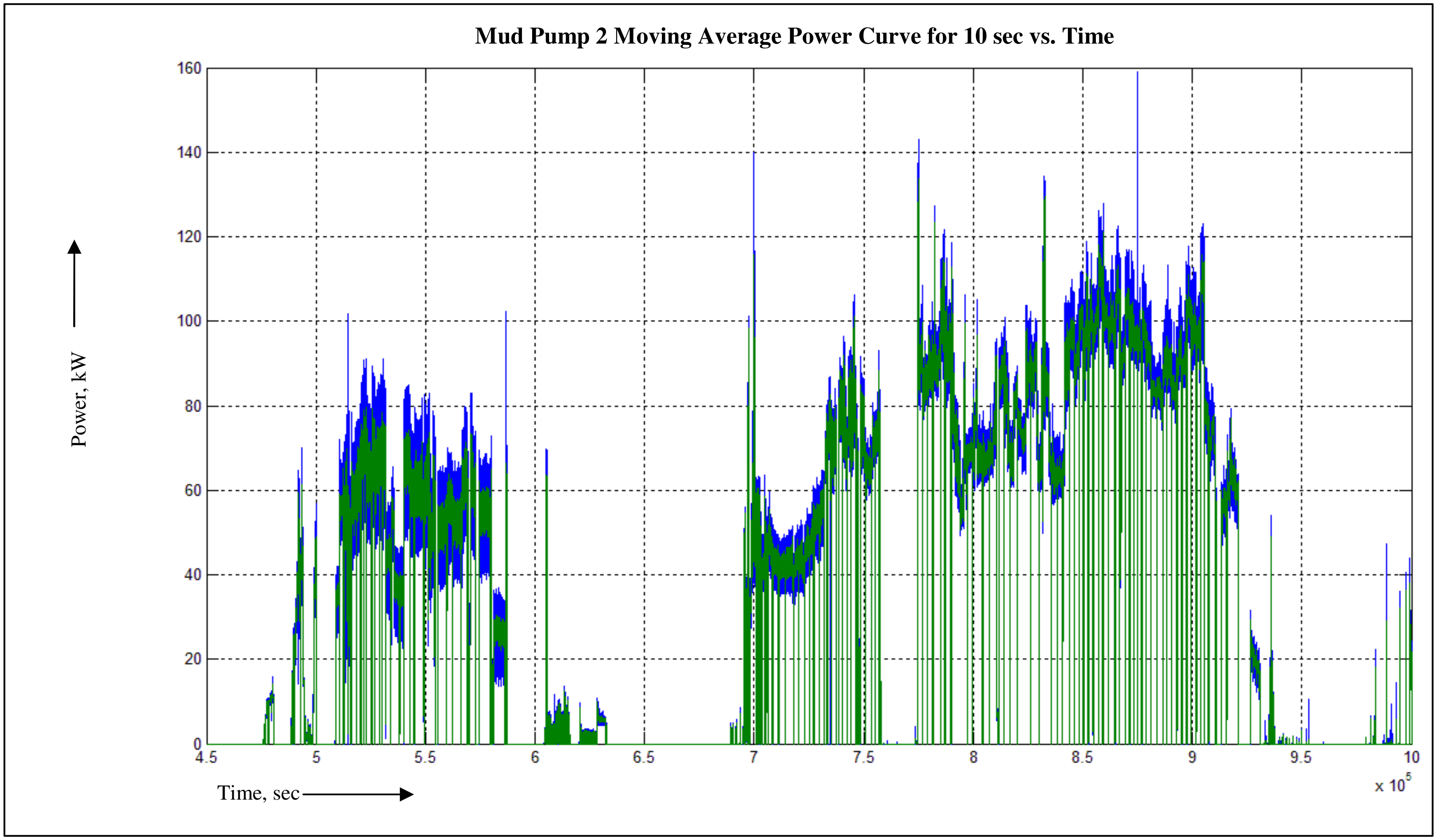


Figure A4 - Mud Pump 2 instantaneous power (blue) and moving average (green) of window length 10 seconds.

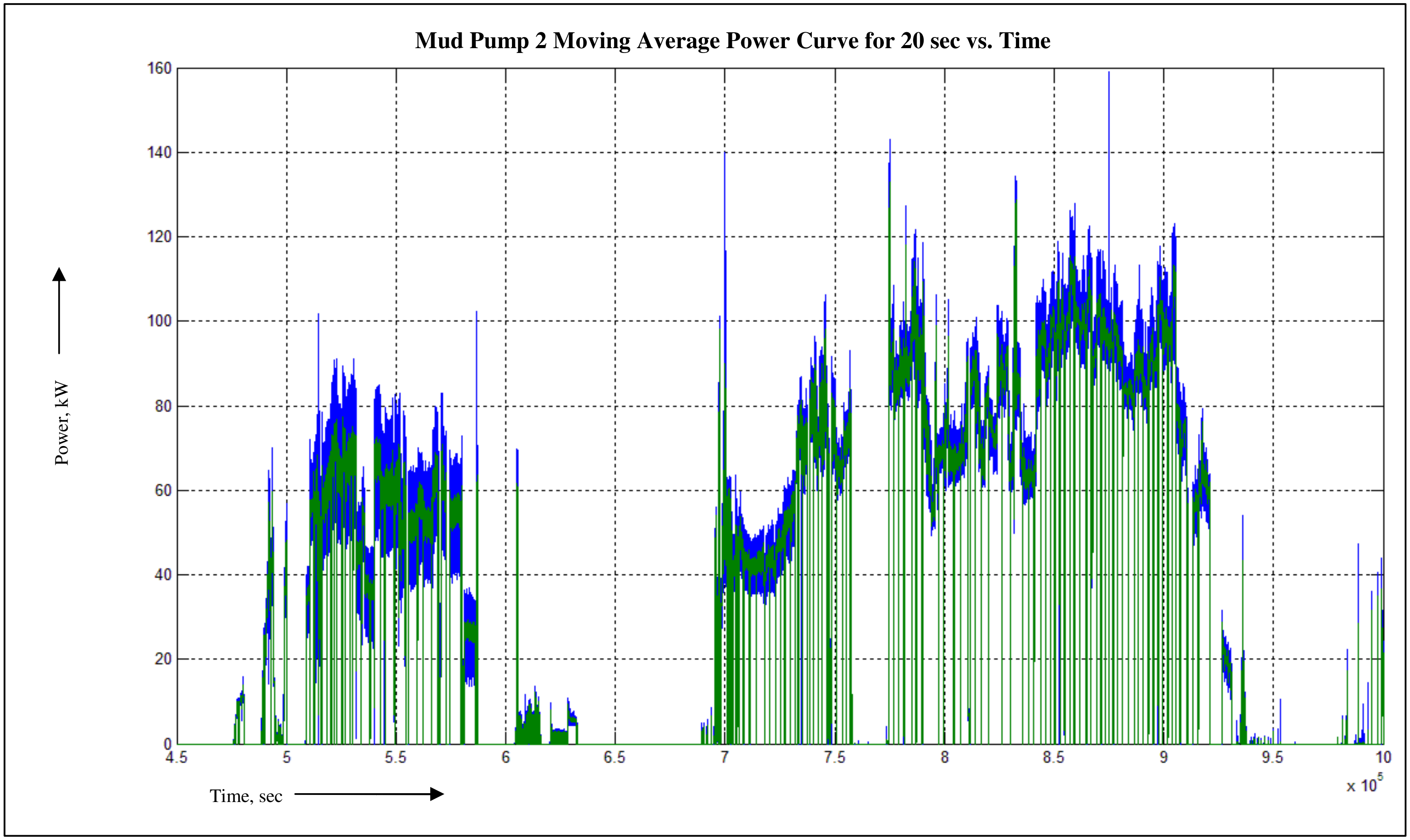


Figure A5 - Mud Pump 2 instantaneous power (blue) and moving average (green) of window length of 20 seconds

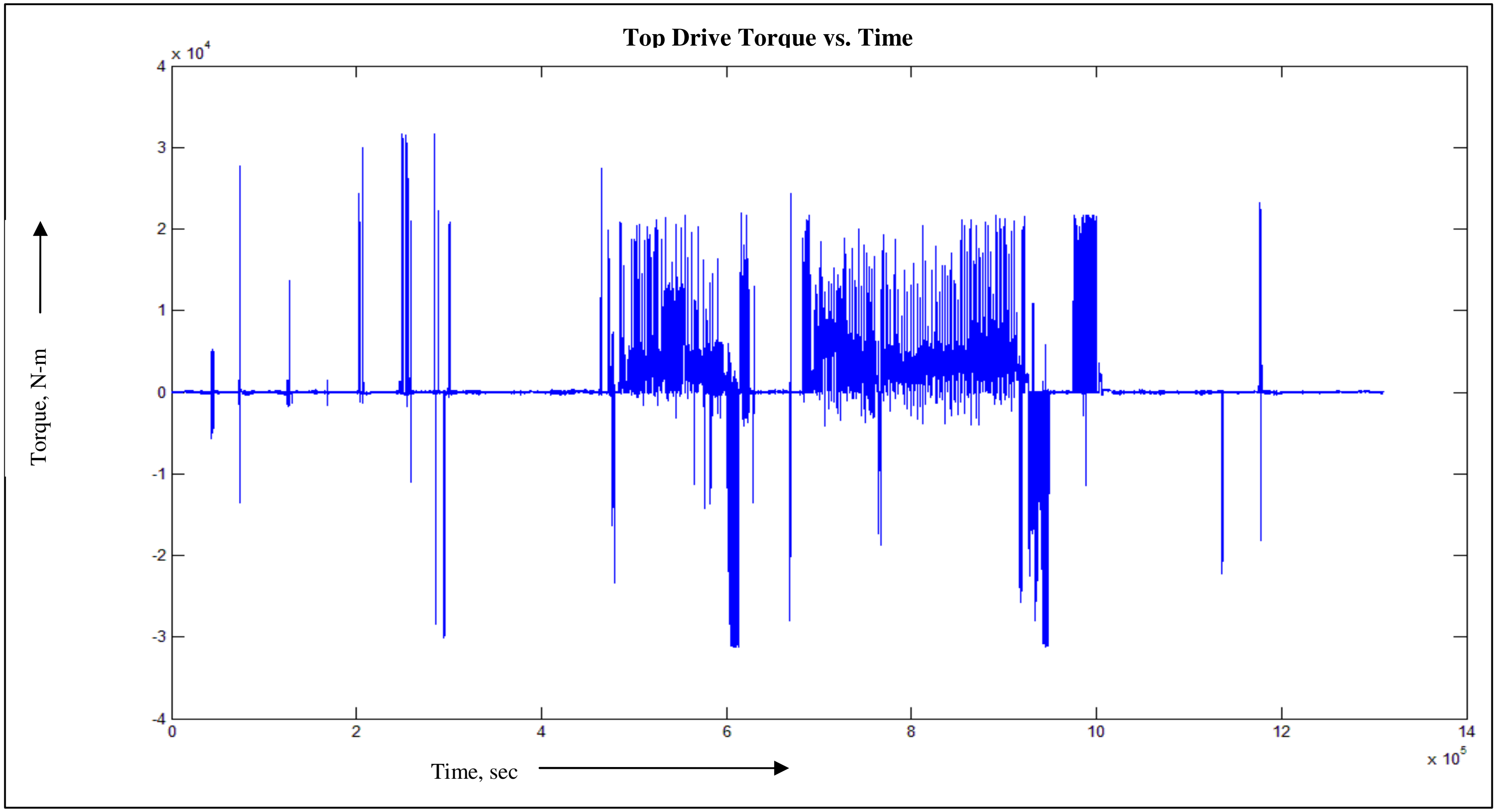


Figure A6 - Top Drive torque variations in N-m with time

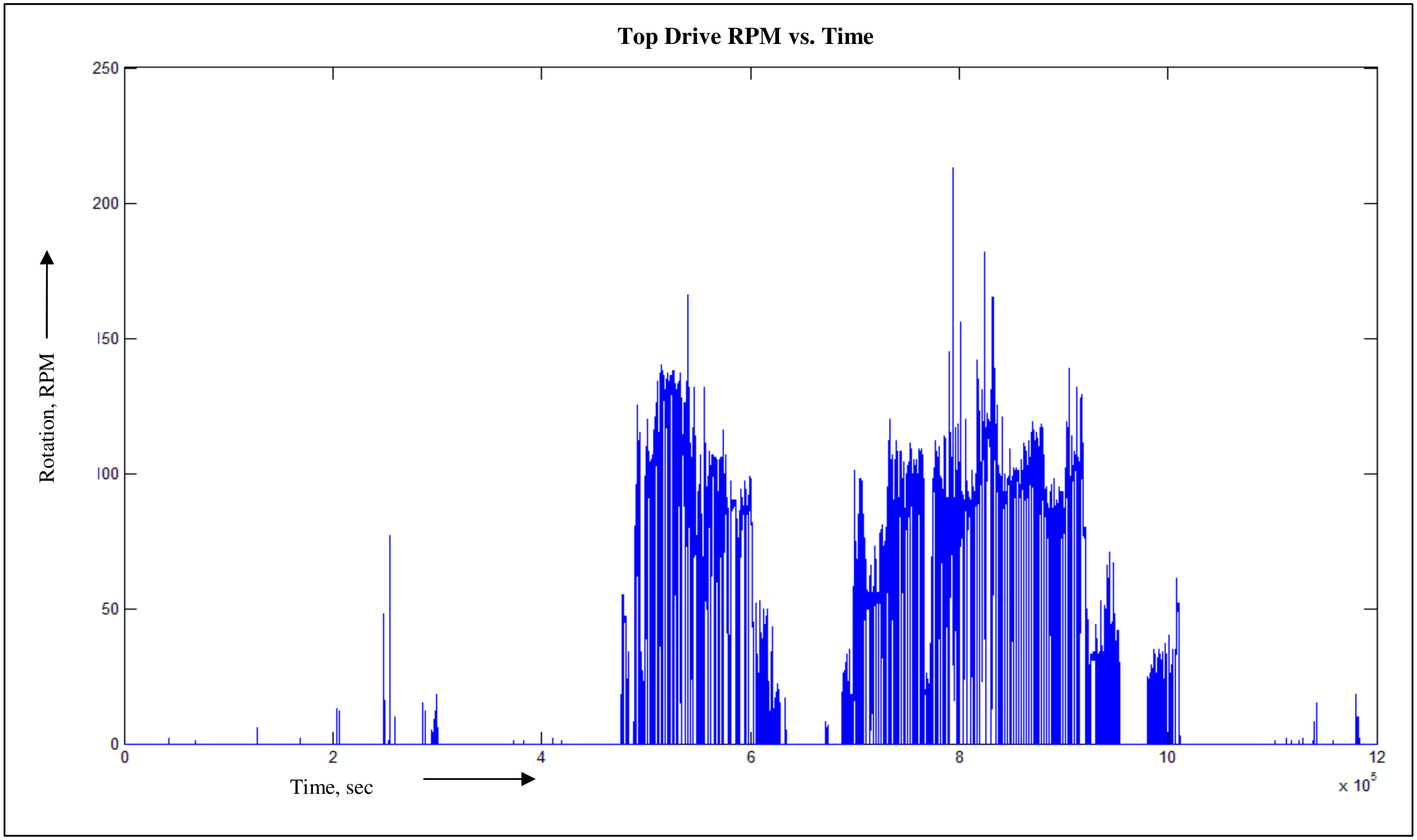


Figure A7 - Top drive RPM with time

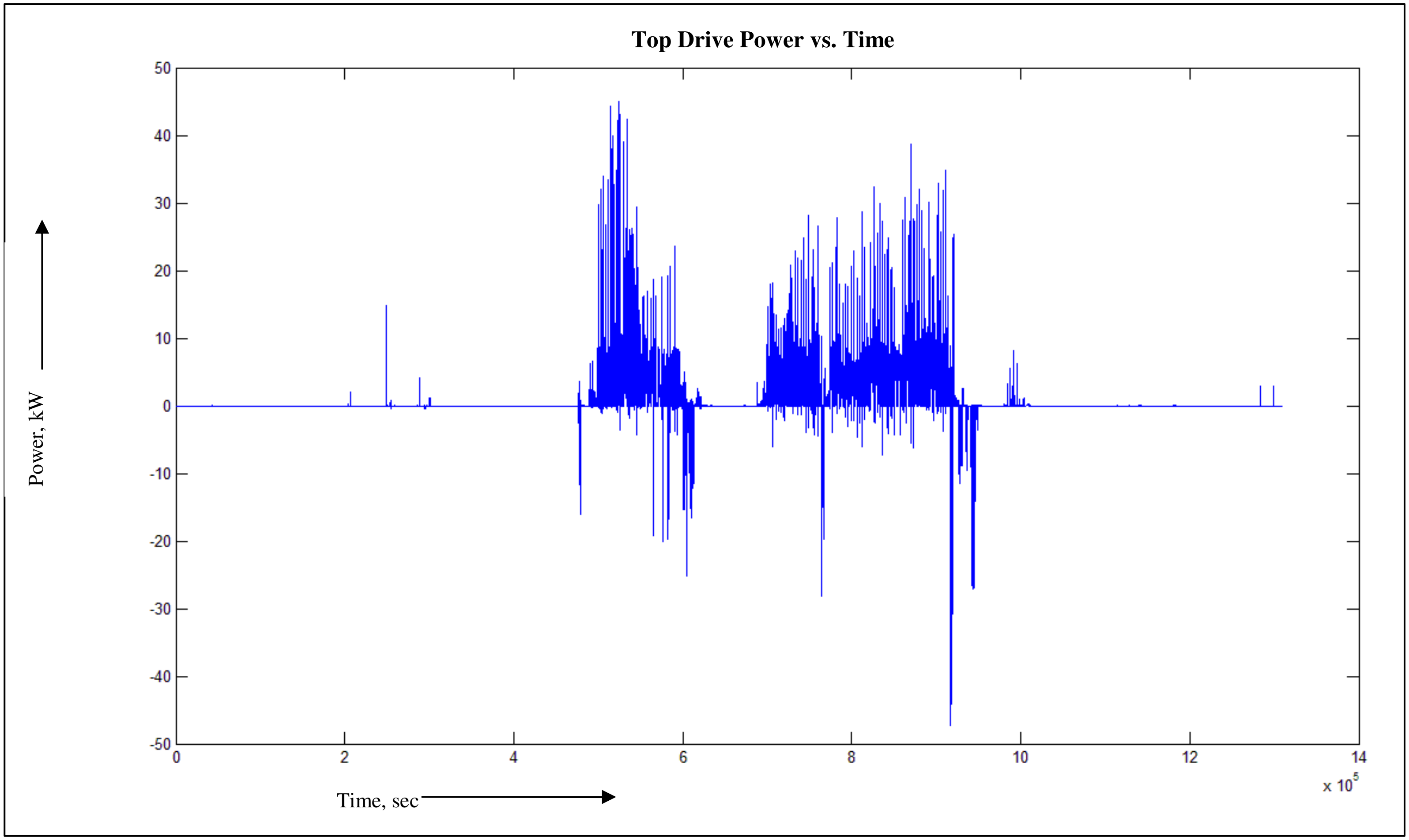


Figure A8 – Top Drive instantaneous power (blue)

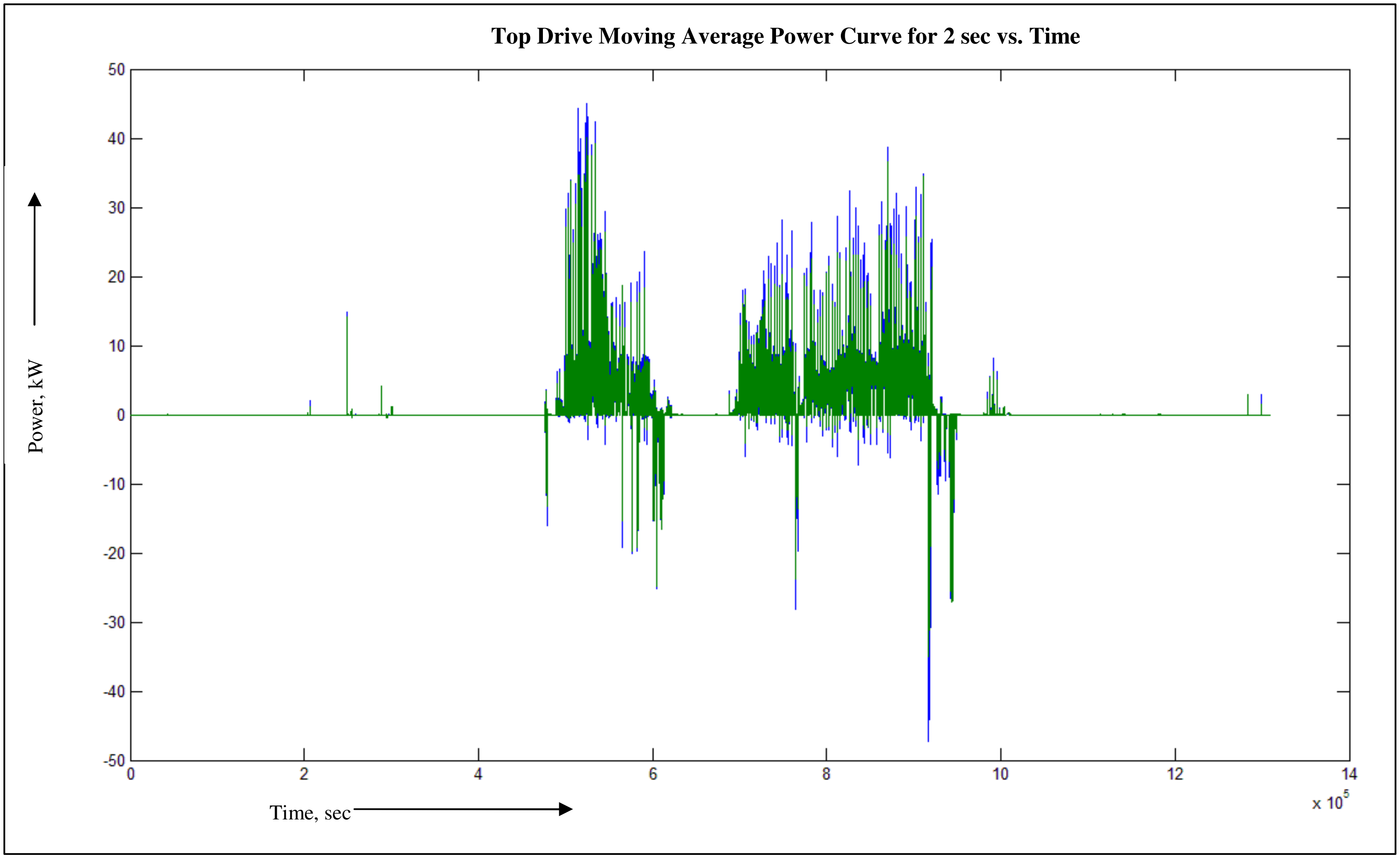


Figure A9 - Top Drive instantaneous power (blue) and moving average (green) of window length 2 seconds

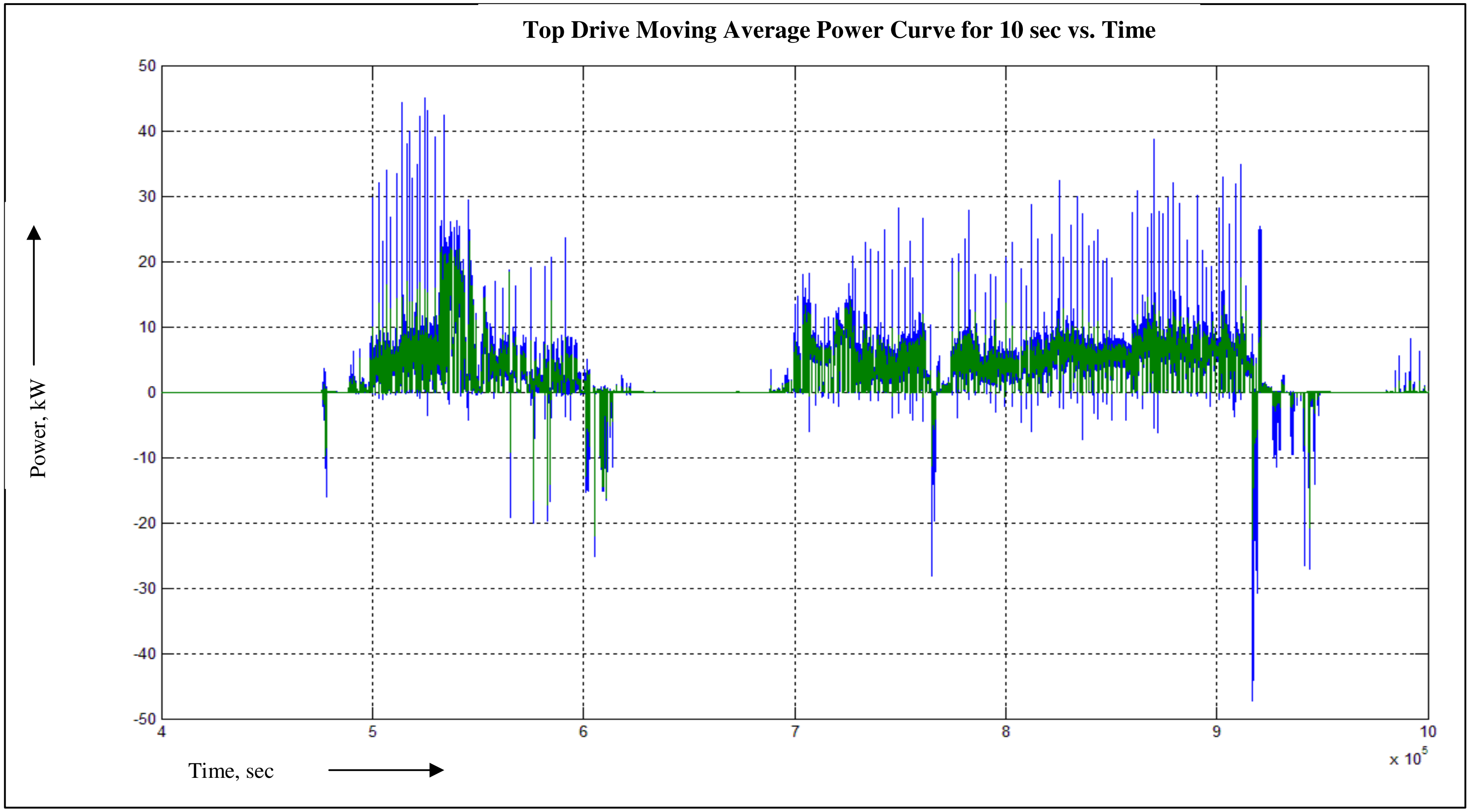


Figure A10 - Top drive instantaneous power (blue) and moving average (green) of window length 10 seconds

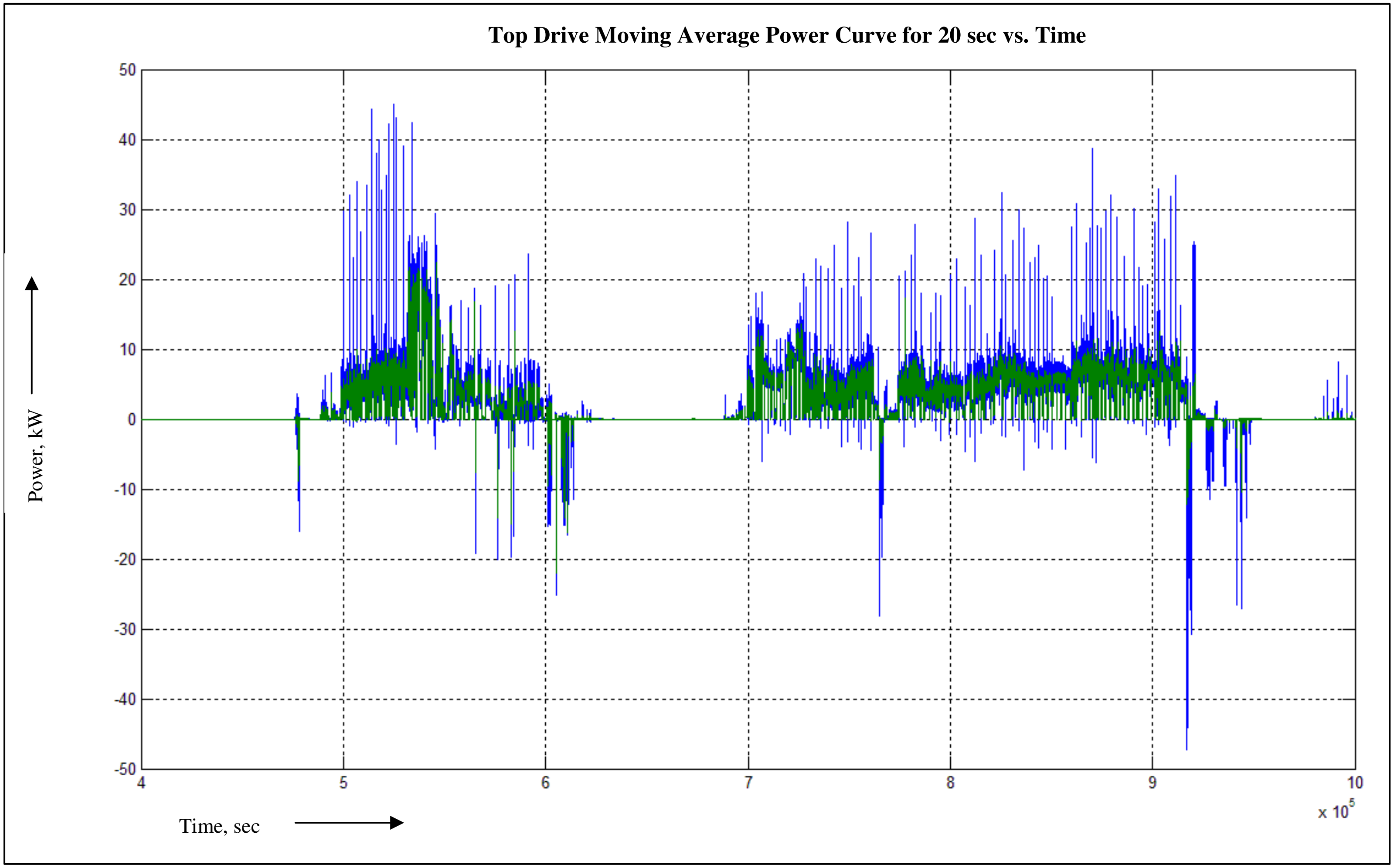


Figure A11 – Top Drive instantaneous power (blue) and moving average (green) of window length 20 seconds

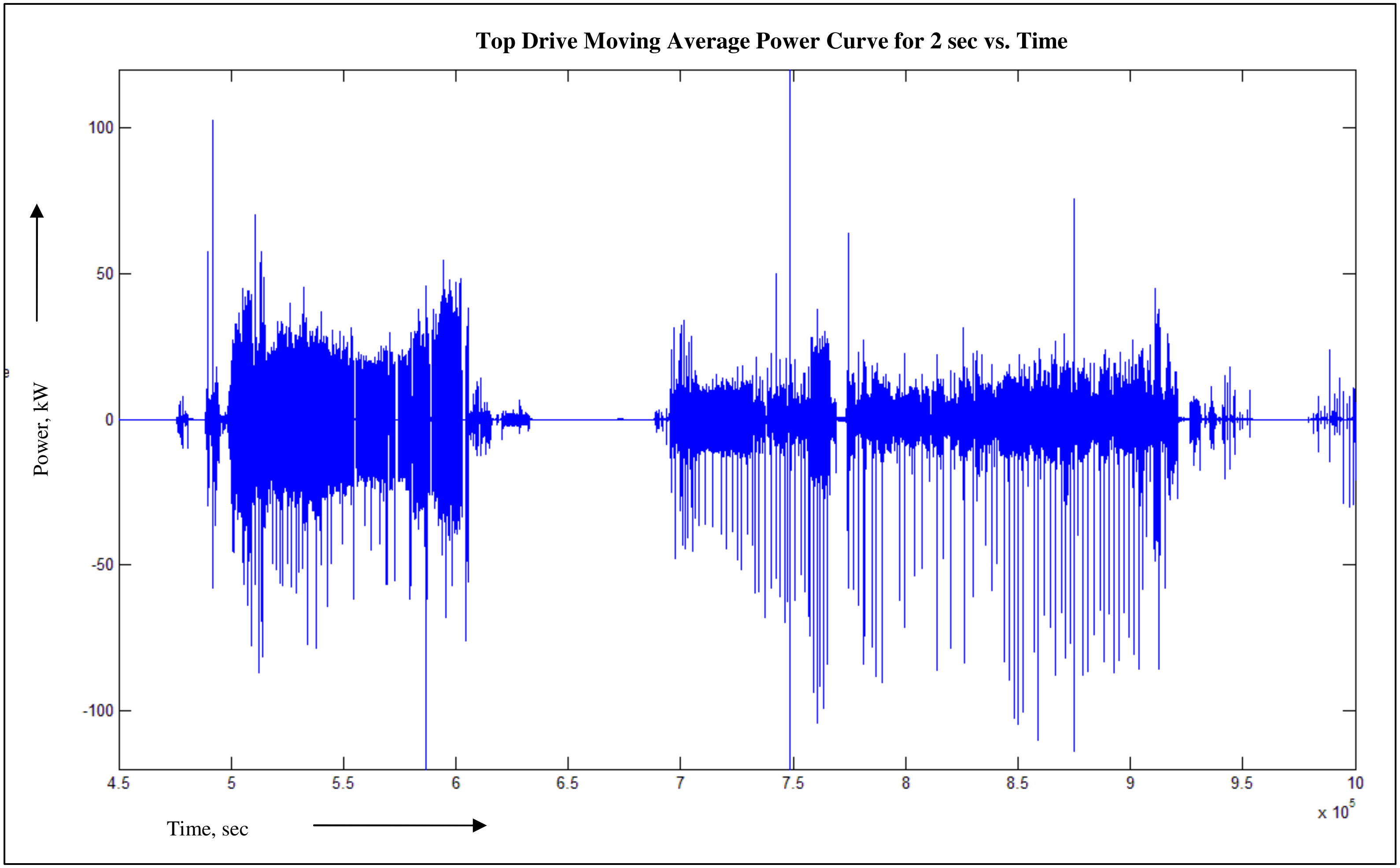


Figure A12 - Difference between instantaneous power and moving average curve for mud pumps and top drive , 2sec

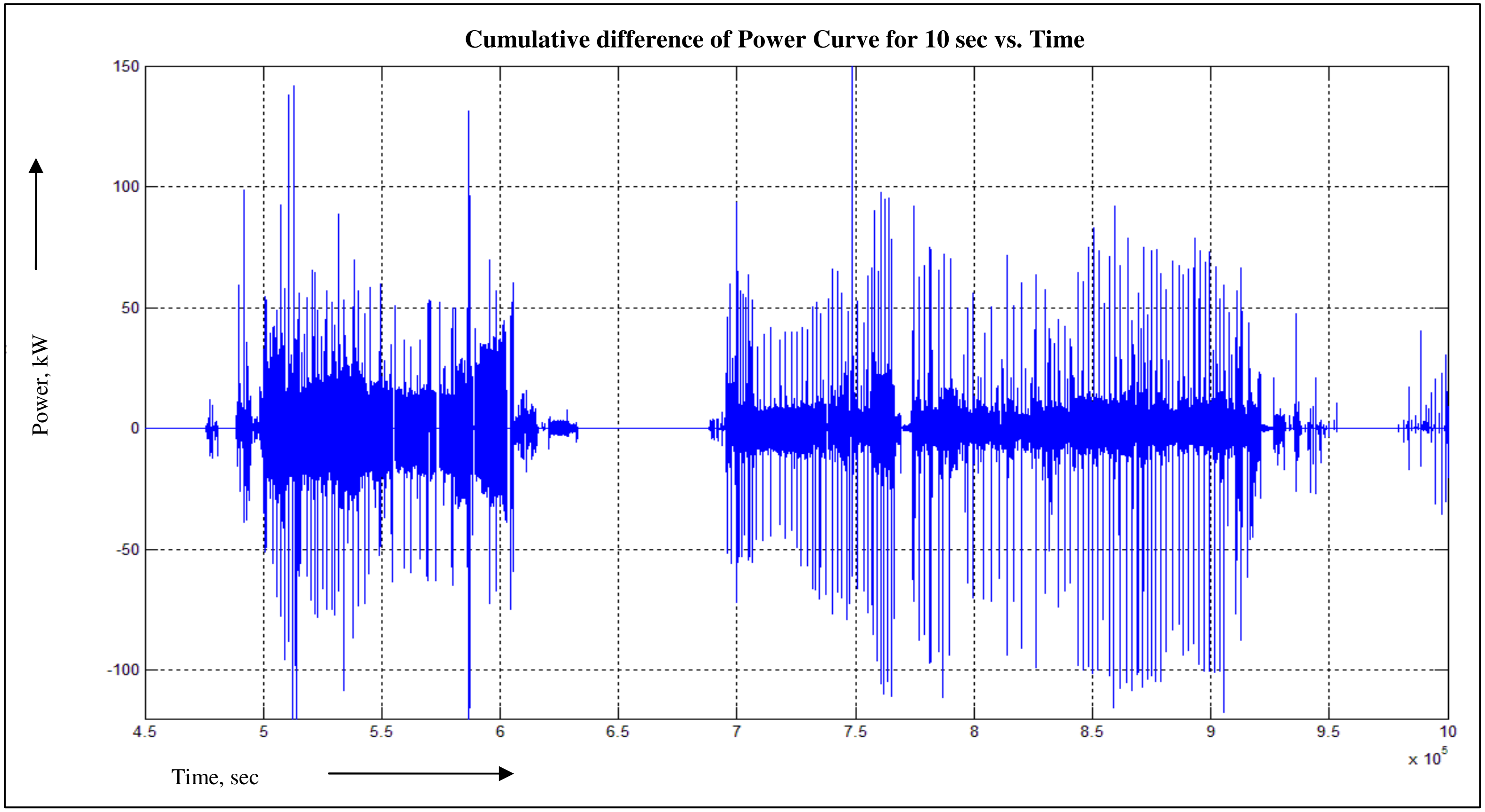


Figure A13 - Difference between instantaneous power and moving average curve for mud pumps and top drive, 10 sec

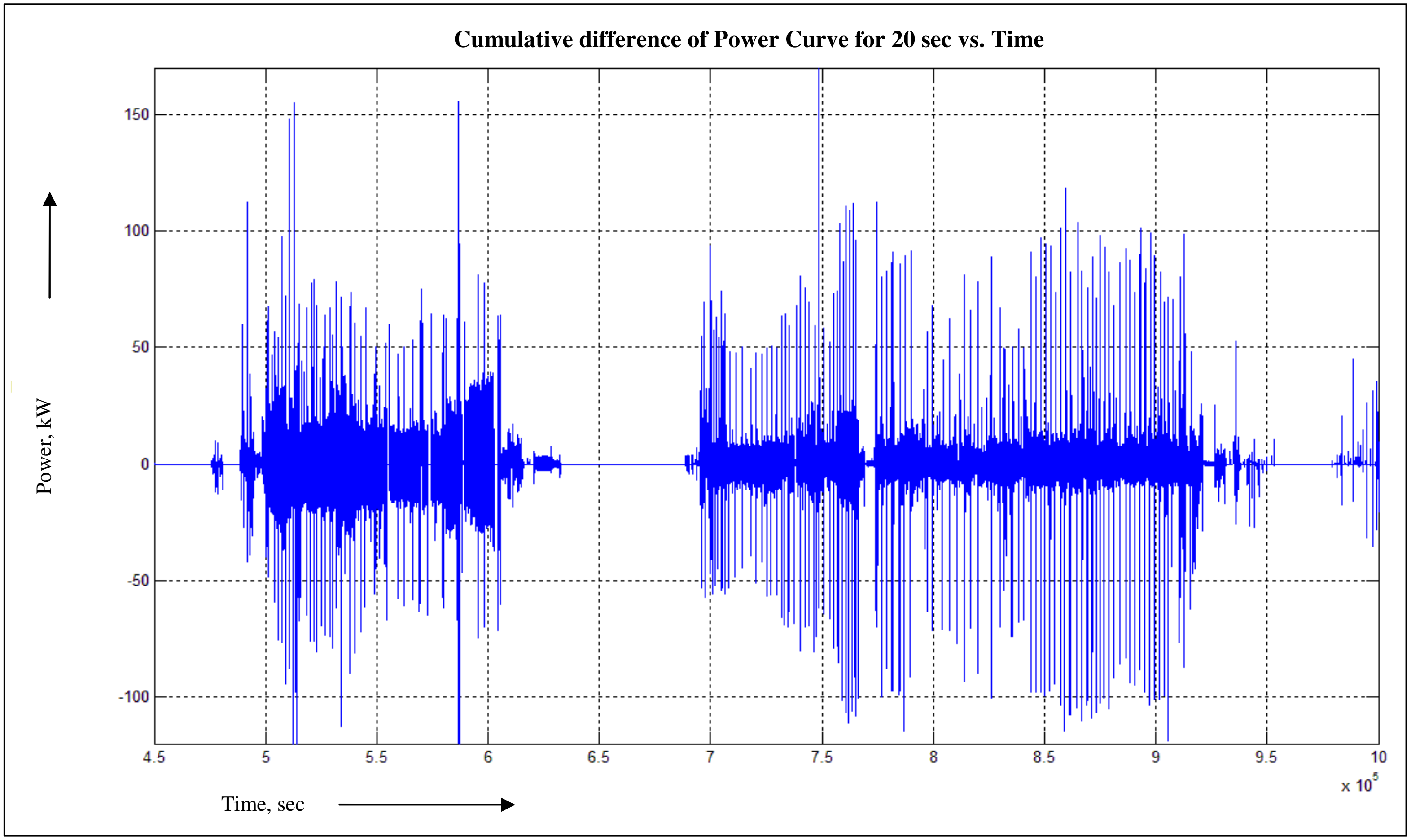


Figure A14 - Difference between instantaneous power and moving average curve for mud pumps and top drive , 20sec

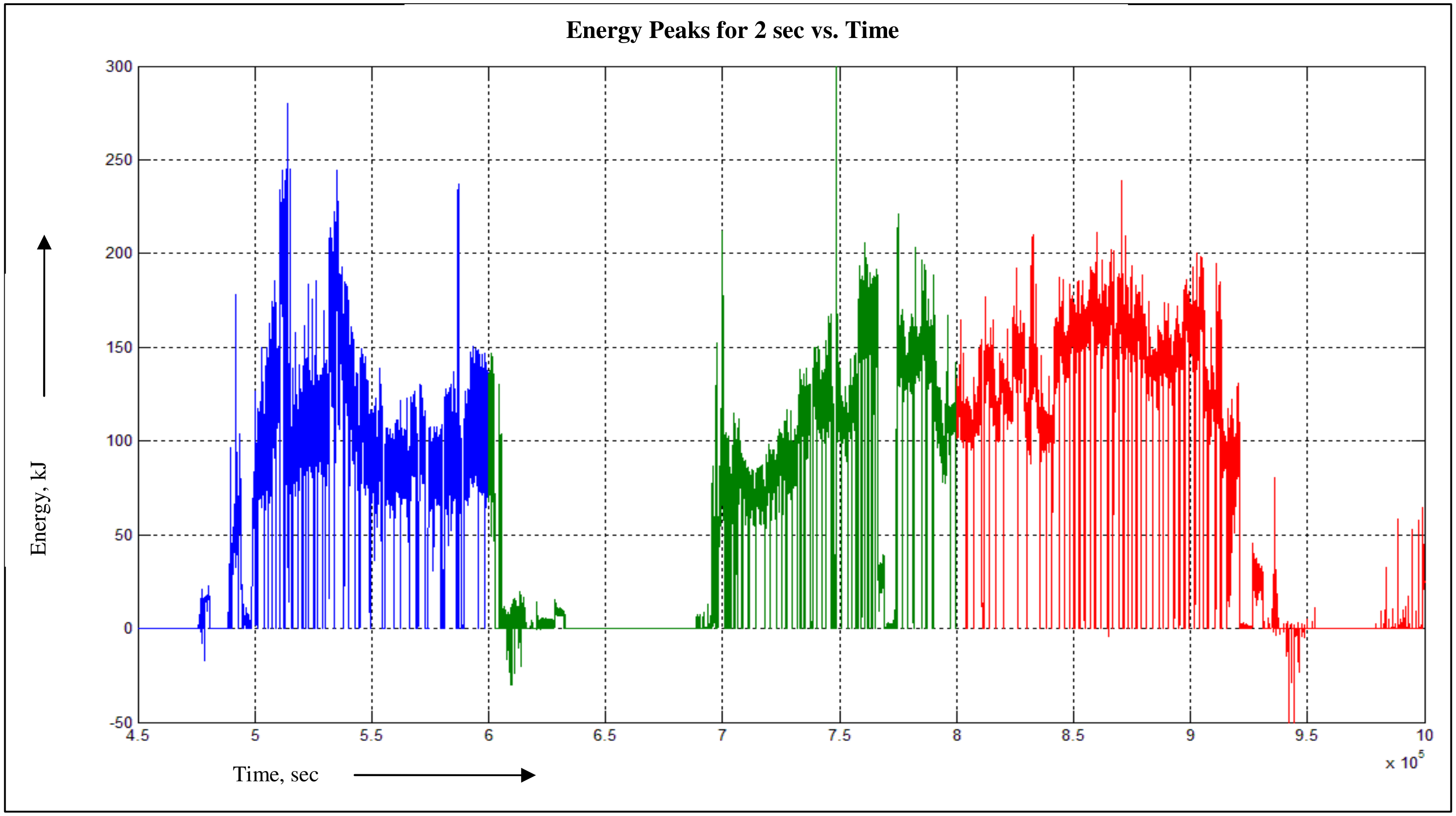


Figure A15 - Overall Energy curve for window length of 2sec (KERS system should be able to provide)

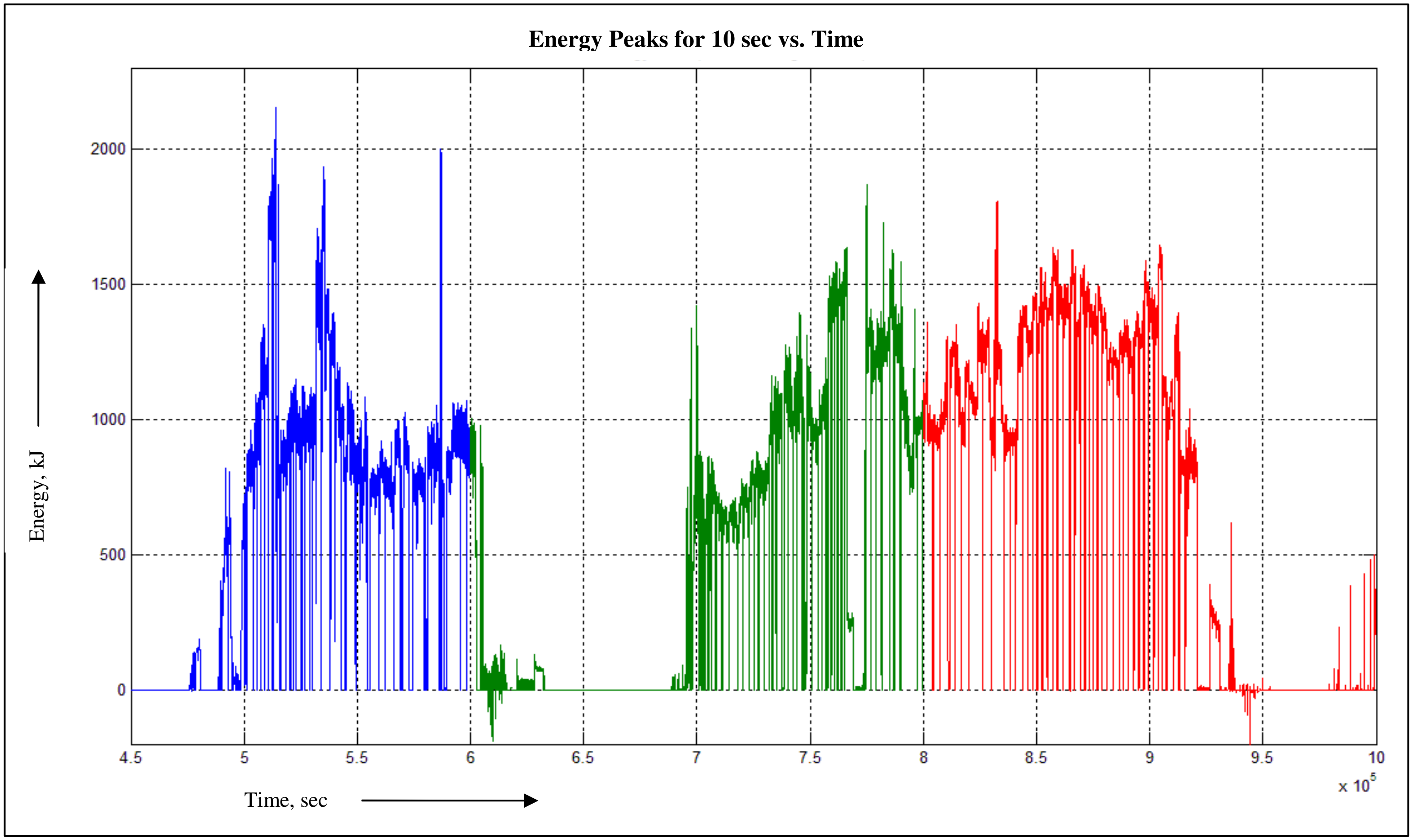


Figure A16 - Overall Energy curve for window length of 10sec (KERS system should be able to provide)

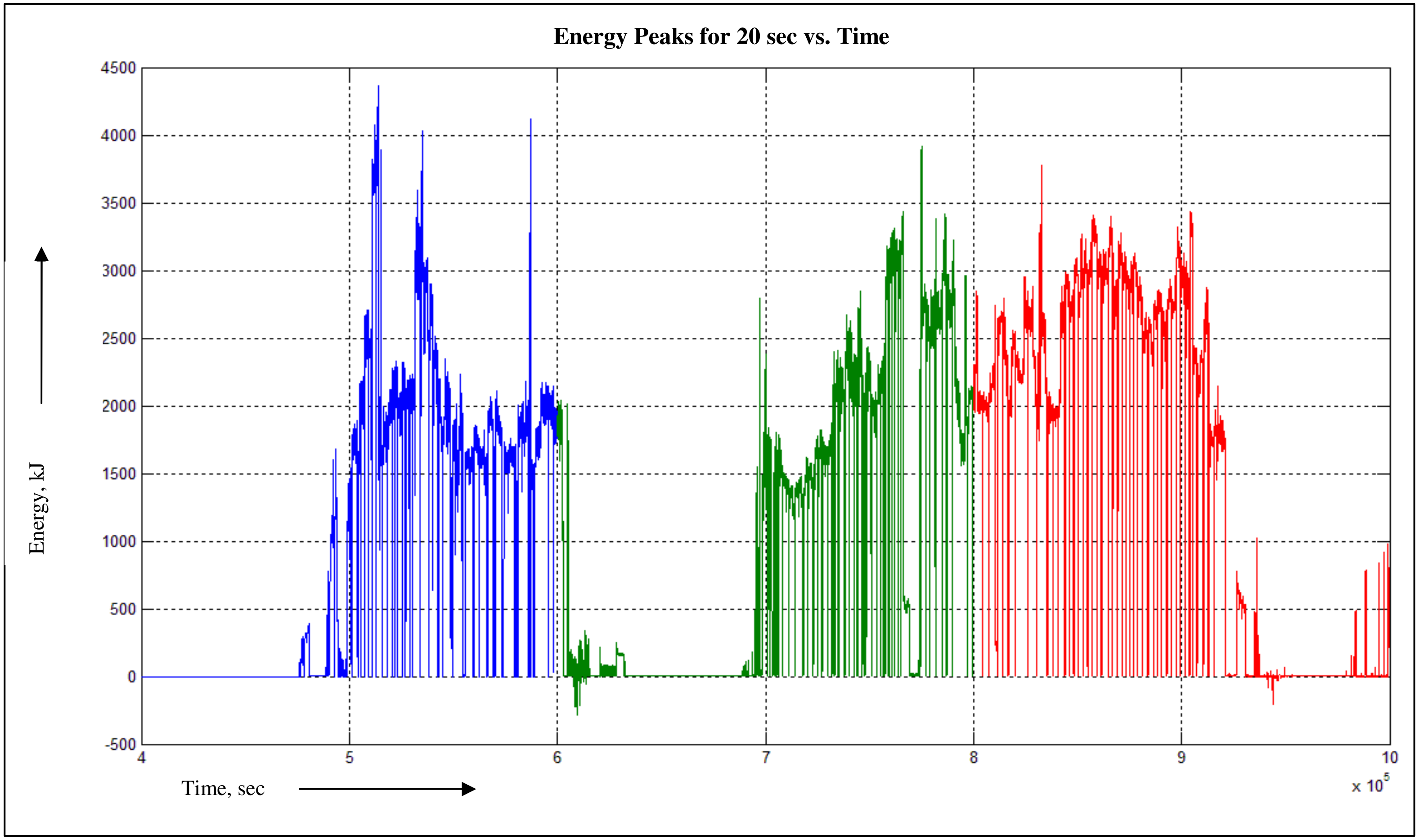


Figure A17 - Overall Energy curve for window length of 20sec (KERS system should be able to provide)

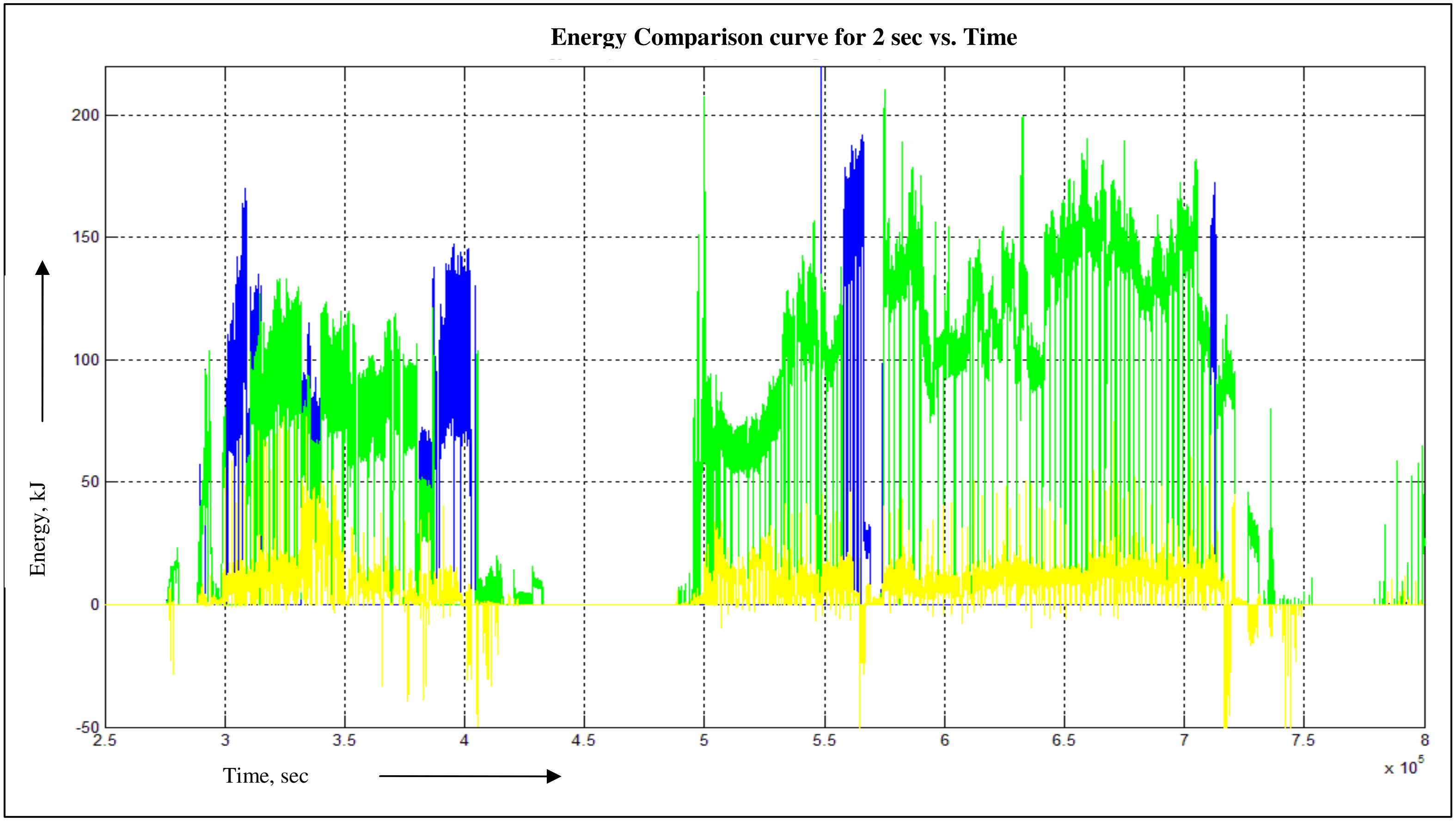


Figure A18 - Energy comparison curve for mud pumps and top drive for a window length of 2 seconds

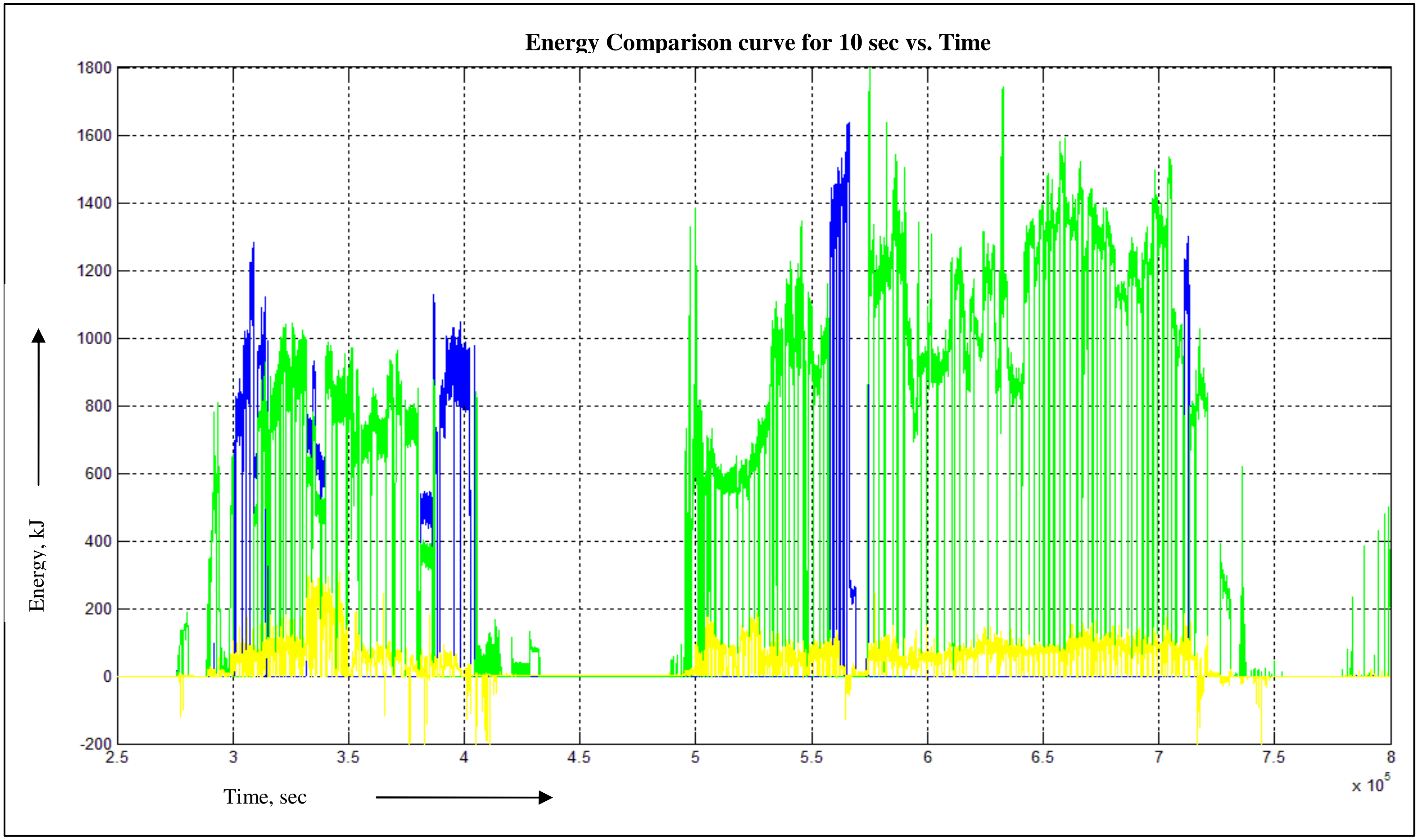


Figure A19 - Energy comparison curve for mud pumps and top drive for a window length of 10 seconds

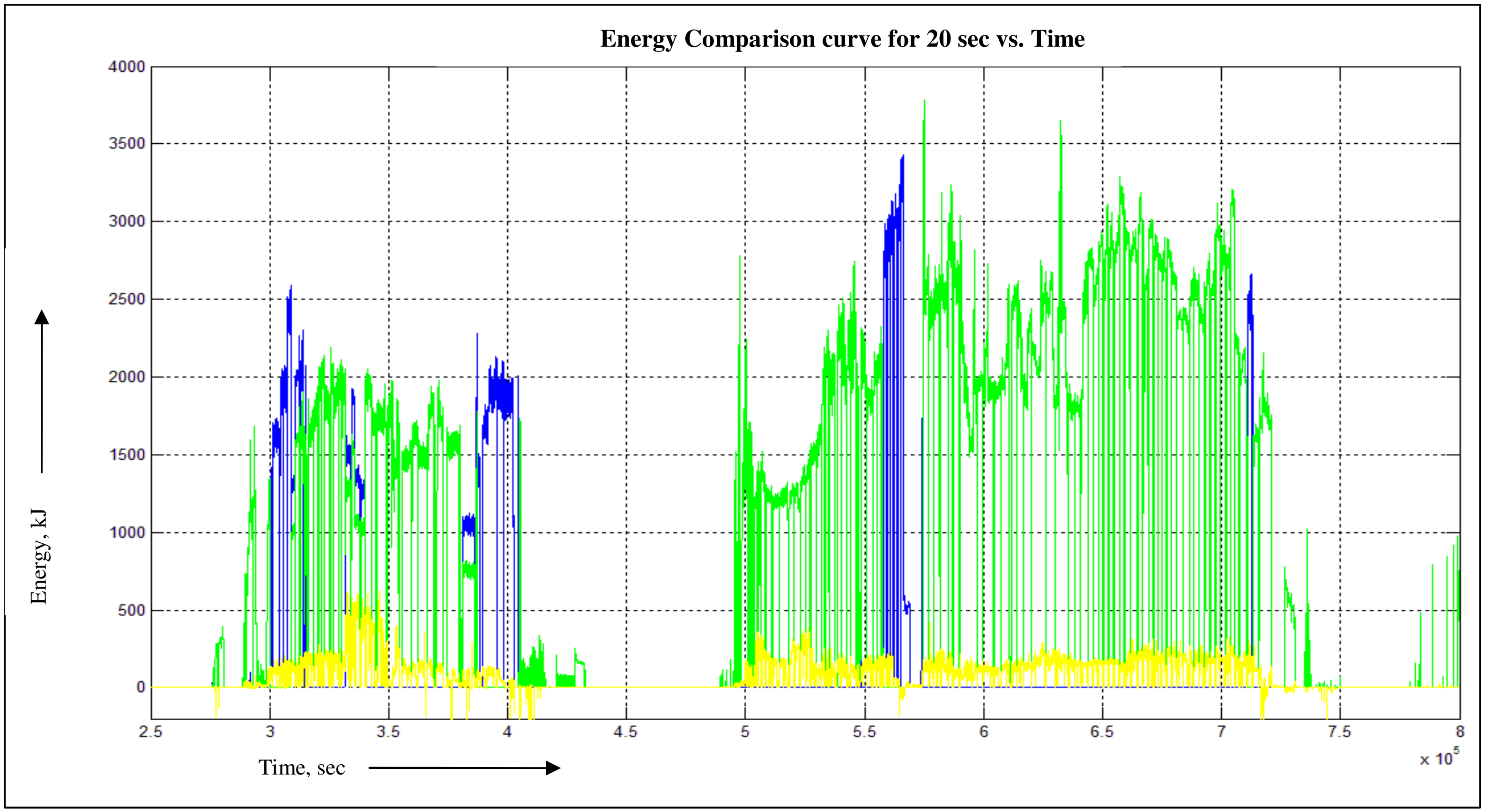


Figure A20 - Energy comparison curve for mud pumps and top drive for a window length of 20 seconds

VITA

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