Yaskawa Electric America Training Café

Today's topic is

The Cost of Stopping

Presenter is

Joe Pottebaum

Senior Applications Engineer

To make this Café enjoyable for all, please follow these tips on web class etiquette.

Please do not put us on hold*. Others will hear the hold music.*

Do not use a speaker phone*. Background noise can be heard.*

Don't be shy, we welcome comments and questions.
(Press ****6**** *to* ***mute or unmute*** *your phone)*

Questions not answered during the Café can be emailed to ***training@yaskawa.com*** *or can be entered into the survey at the end of the class.*

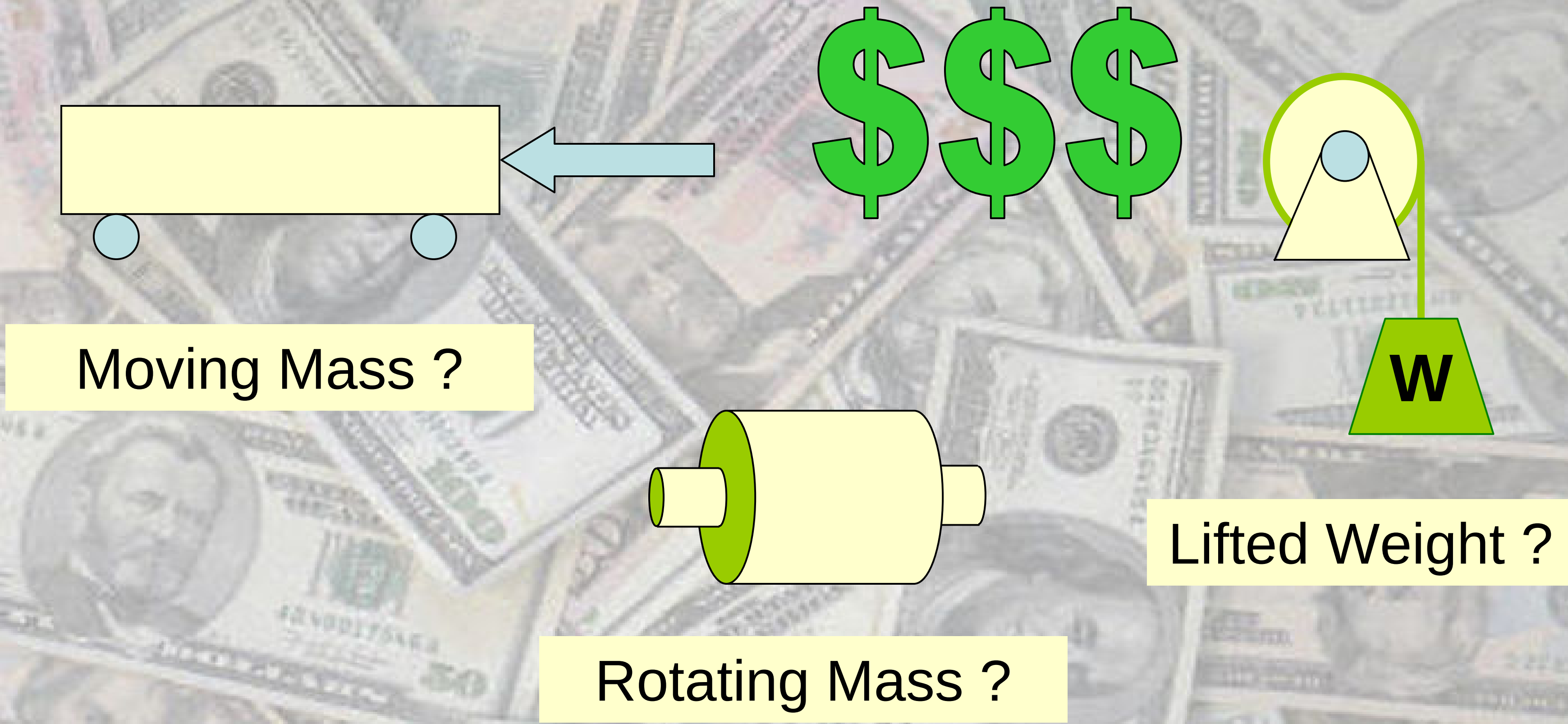
Where Do You Store Your Money?

$$$

A Great Financial Institution?

Under the Mattress?

Where is Your Money Stored?

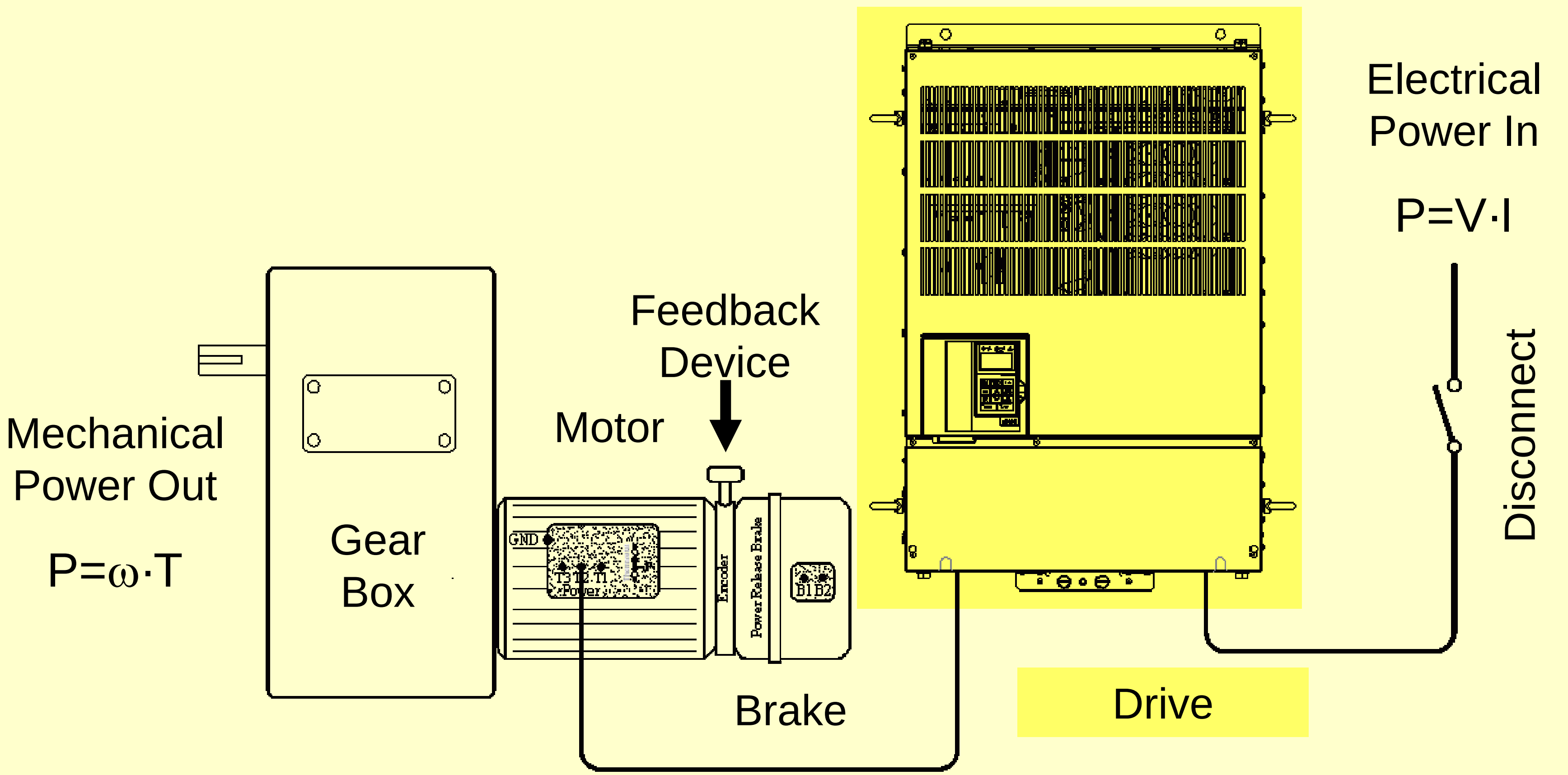


Recoverable Energy

- *Recoverable Energy*
  - *Anything that takes a brake to stop*
- *Non-Recoverable Energy*
  - *Heat, Sound, Light, Fluid Turbulence*

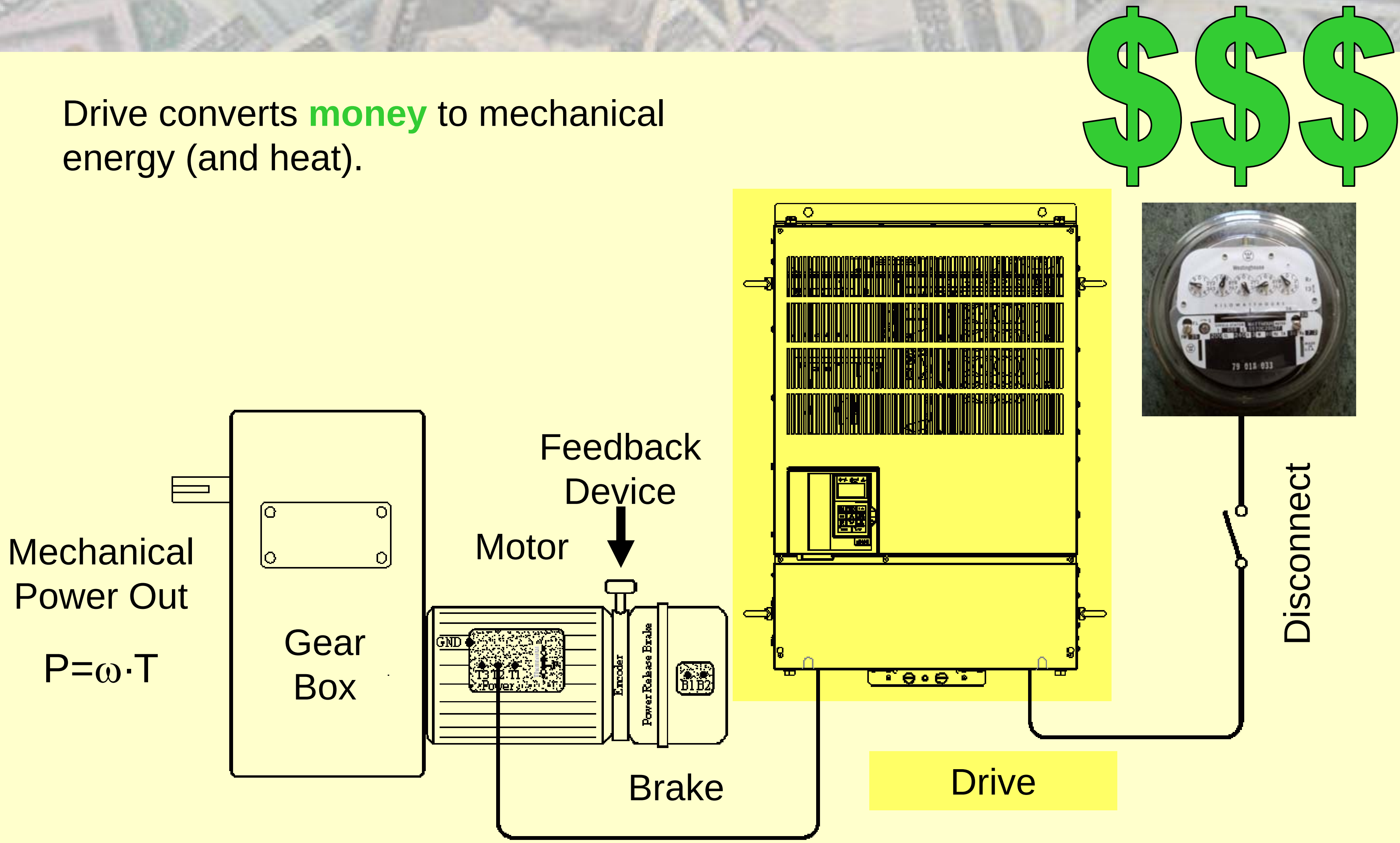
The Drive as Power Converter

Drive converts electrical energy to mechanical energy (and heat).



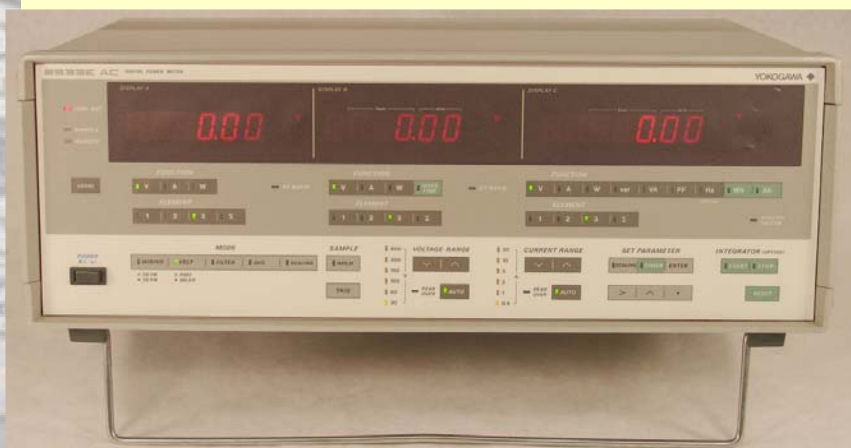
The Drive as Money Converter

Drive converts **money** to mechanical energy (and heat).



Kilowatts and Kilowatt·hours

- *Wattmeters measure average Power.*

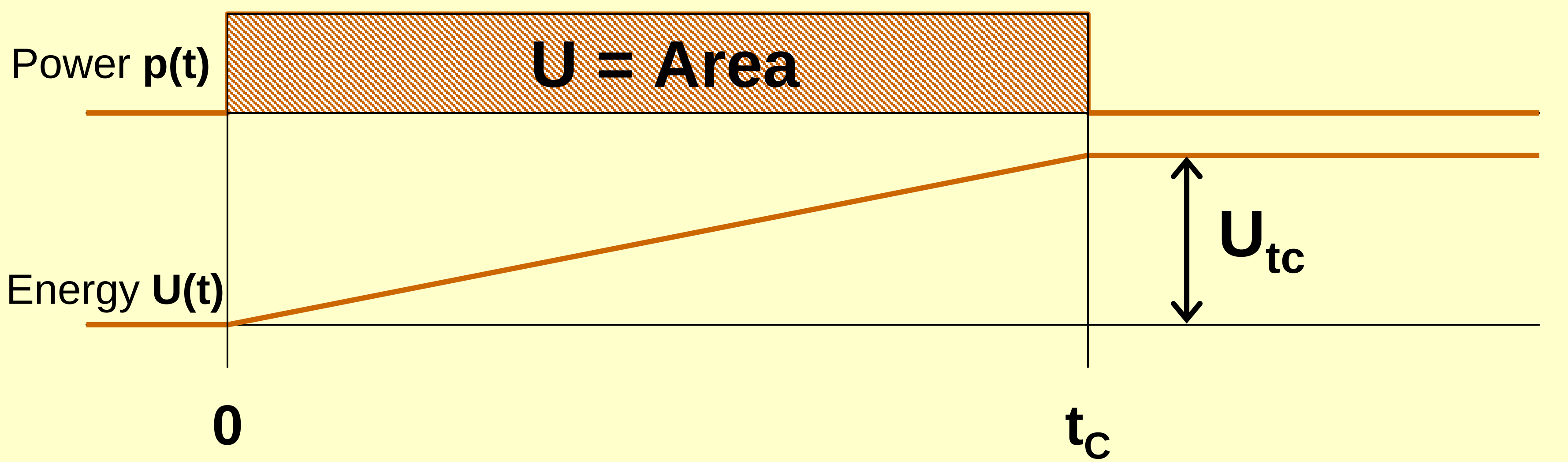


- *Watthour meters measure Energy.*

- ***Energy*** *(U_{tc}) is the* ***Integral of Power*** *(p) over time 0 to t_C.*

$$U(t) = \int_0^t p(t) \cdot dt$$

$$\text{Average Power} = \frac{U_{t_c}}{t_C} = \frac{\int_0^{t_c} p(t) \cdot dt}{t_C}$$



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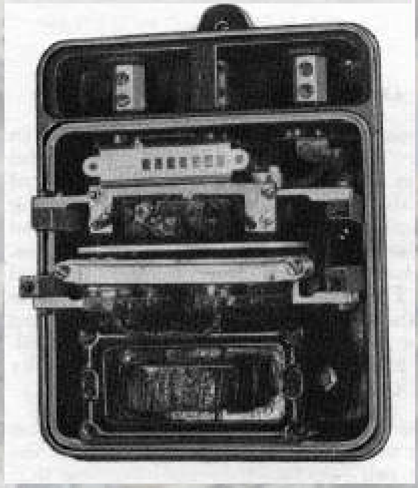
Shallenberger Integrating Wattmeter (1894 to 1897)

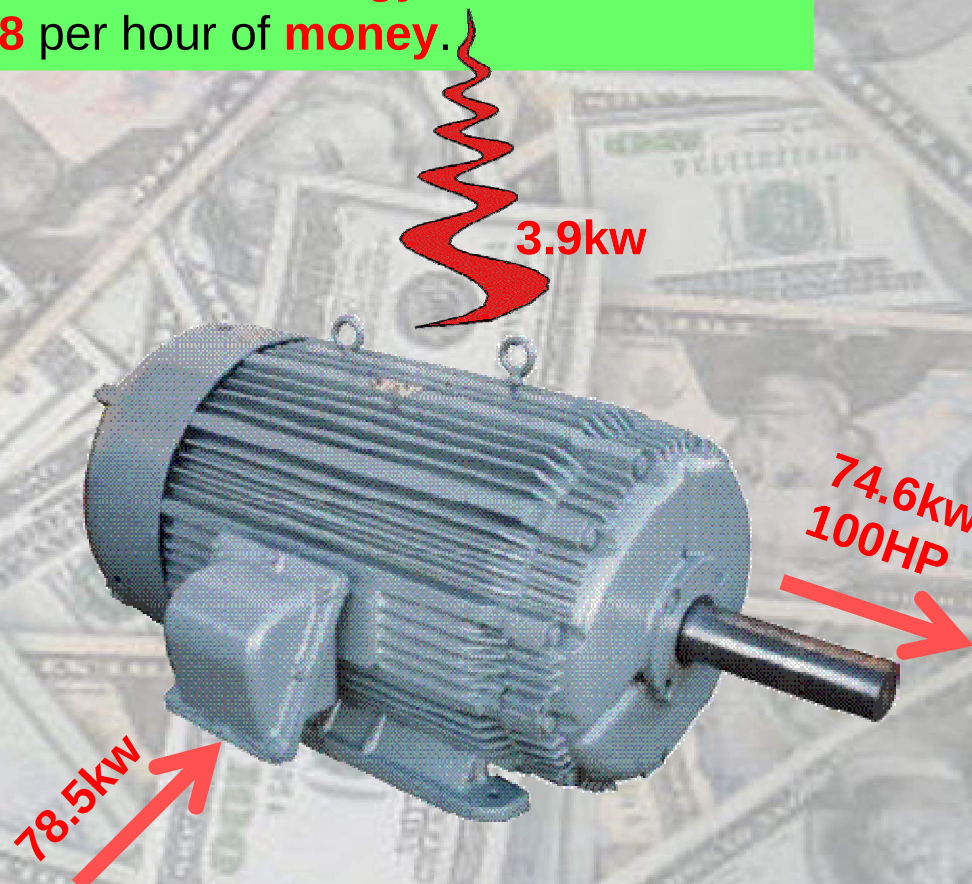
By the mid-1890s, Shallenberger's ampere-hour meter was popular but because of the increasing use of motors, a true watthour meter was needed to account for varying voltages and power factors. Shallenberger rose to the challenge and came up with a new meter which was the first commercially produced induction watthour meter. It was large, heavy (41 pounds!), and more than twice as expensive as comparable meters in its time. This meter was one of the first models to use a cyclometer register. Depending on the customer's preference, this register was equipped with 4 drums (registering in kwh) or 7 drums (registering in watthours). The stator was similar to ones in later meters with its voltage and current coils arranged on opposite sides of the disk and had a magnet assembly to damp the disk's speed.



From http://watthourmeters.com/westinghouse/shall-watt.html

Cost to Run a Motor

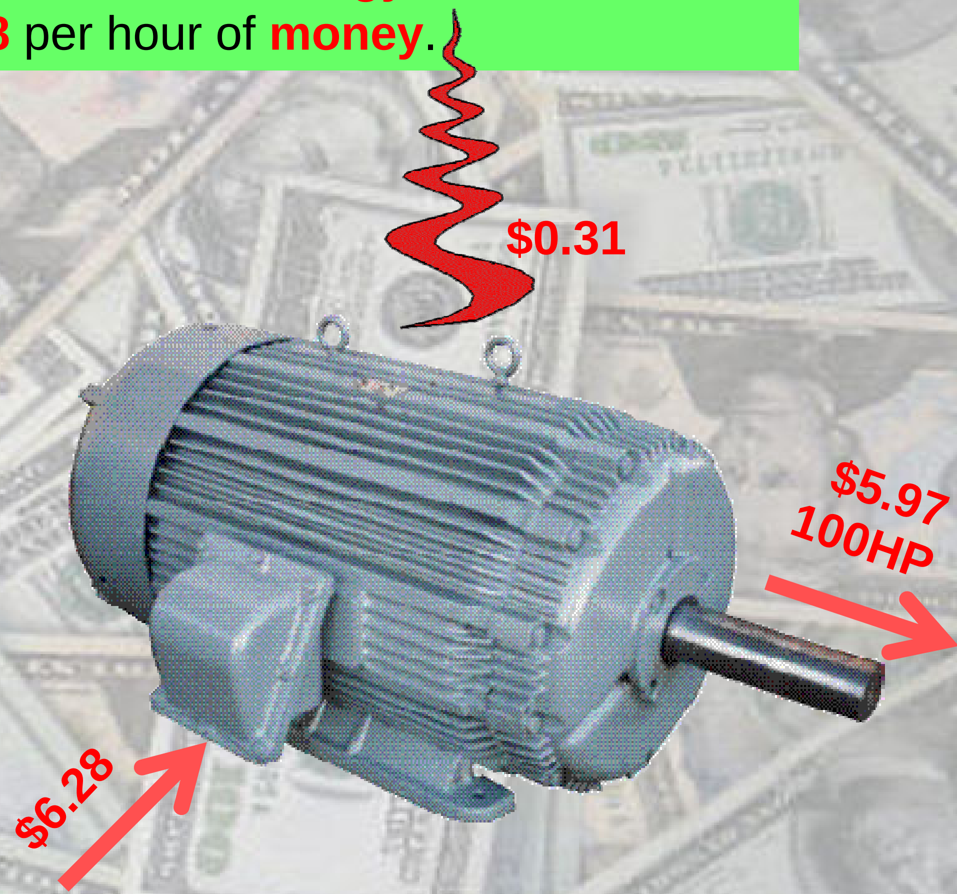
A 100HP motor fully loaded producing 74.6 kw of **power** for 1 hour with and efficiency of 95% will consume 78.5 kwh of **energy**.
At **$0.08 per kwh** it consumes **$6.28** per hour of **money**.



"Money is Power" ?

A 100HP motor fully loaded producing 74.6 kw of **power** for 1 hour with and efficiency of 95% will consume 78.5 kwh of **energy**.
At **$0.08 per kwh** it consumes **$6.28** per hour of **money**.

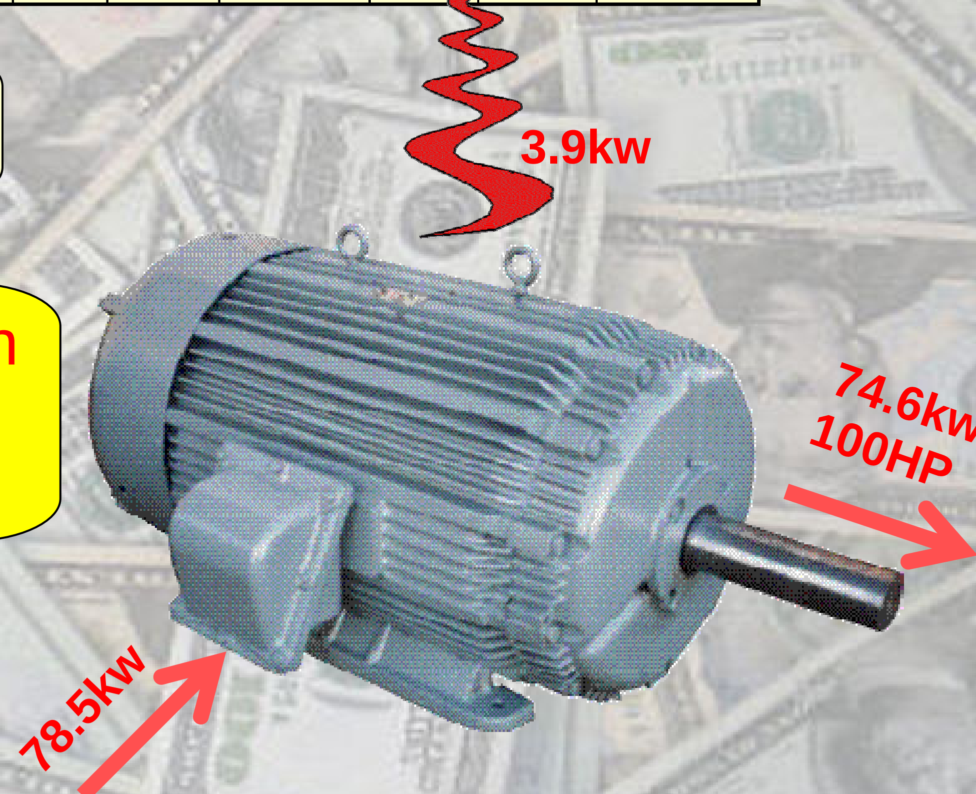
Actually "Money is Energy"



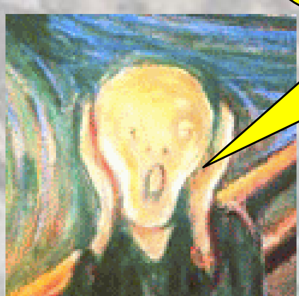
Yearly Cost Continuous Operation

Motor						Cost to Operate						
Output		Eff	Input	ED	Cost	Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	%	$/kwh	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	78.53	100%	$0.08	$6.28	8	1	$50.26	5	50	$12,564
100	74.6	95%	78.53	100%	$0.08	$6.28	8	2	$100.51	5	50	$25,128
100	74.6	95%	78.53	100%	$0.08	$6.28	8	3	$150.77	5	50	$37,693
100	74.6	95%	78.53	100%	$0.08	$6.28	8	3	$150.77	6	50	$45,231
100	74.6	95%	78.53	100%	$0.08	$6.28	8	3	$150.77	7	52	$54,880

Continuous Full Load Operation (ED = 100%)



That's more than I paid for the motor!



Equivalent Duty (ED)

- ***Equivalent Duty** 'ED' is Average Power over time divided by Basis (usually 'rated') Power*

ED is almost like Duty Cycle but not quite.

Load Types Requiring Braking

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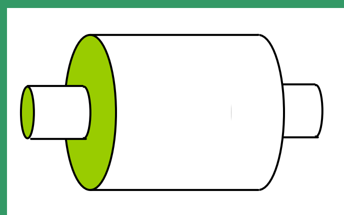
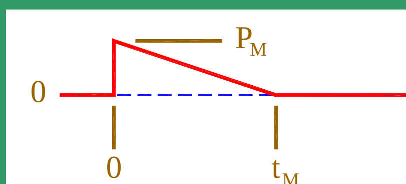
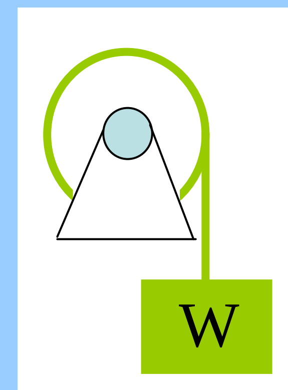
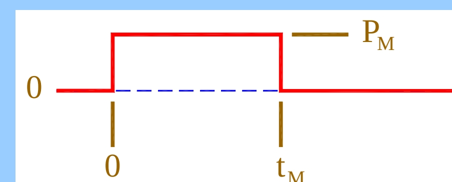
Inertial Load



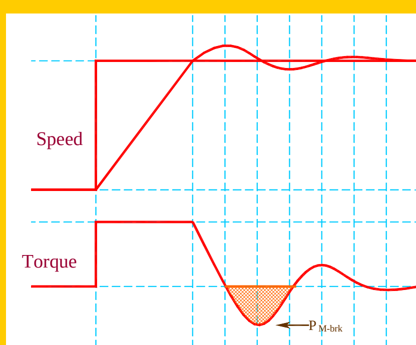


Overhauling Load

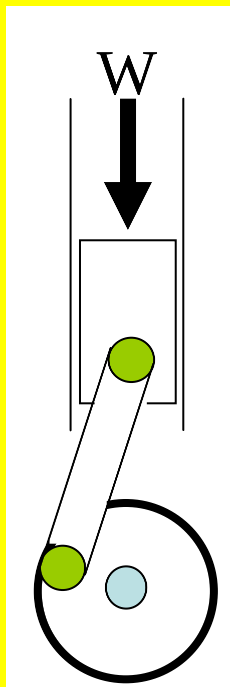


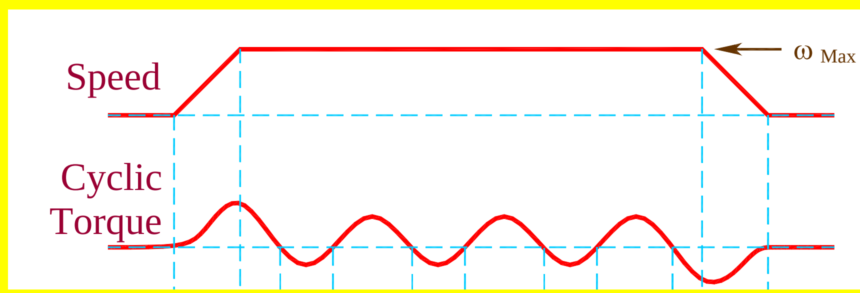


Overshoot



Cyclic Load





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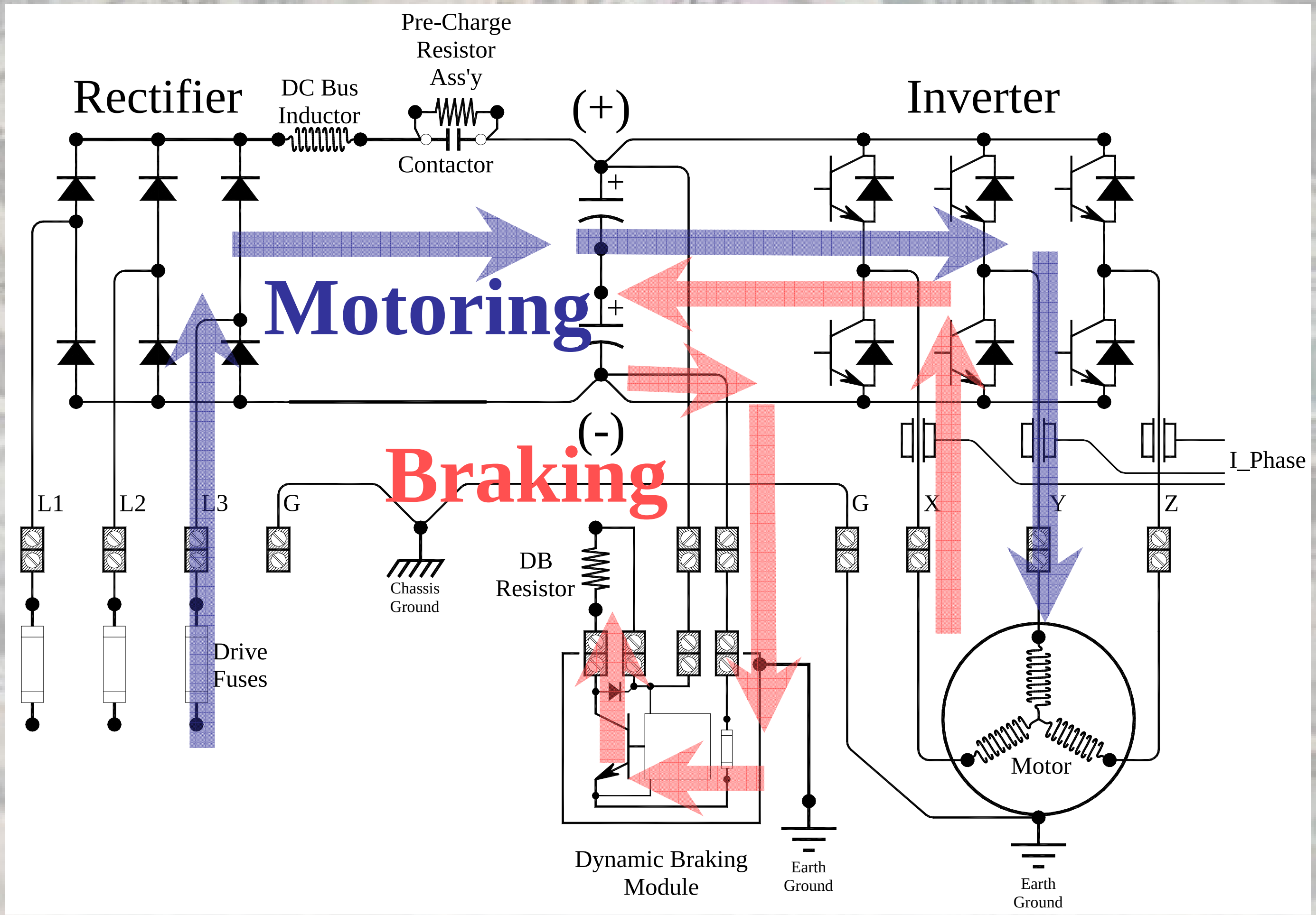
Power Flow : Motoring & Braking



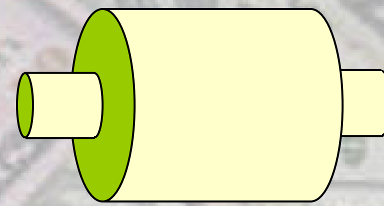
Power = Speed * Torque   Power = Voltage * Current

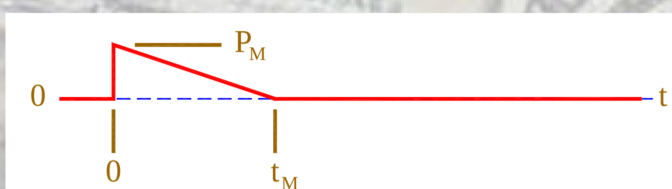
Inertial Load Type

Definition

- *A load that will eventually coast to a stop when power is removed.*

  (like a flywheel)





Braking Profile
(Triangular)

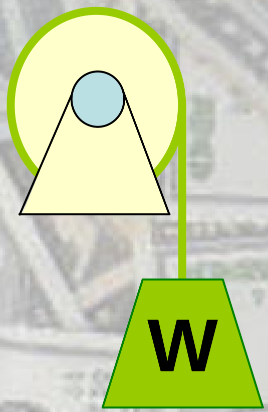
Examples

- *Fans, Pumps*
- *Spindles*
- *Rollers*
- *Horizontal Shuttles*
- *Crane Bridge & Trolley*
- *Ingot Buggies*

Overhauling Load Type

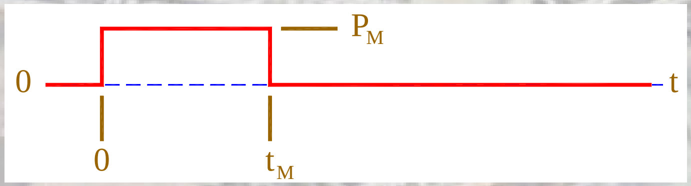
Definition

- *A load that will accelerate when power is removed.* *(usually due to gravity)*



Examples

- *Hoists, Elevators*
- *Product Lifters*
- *Web Tensioners*
- *Stackers*
- *Vertical Indexers*

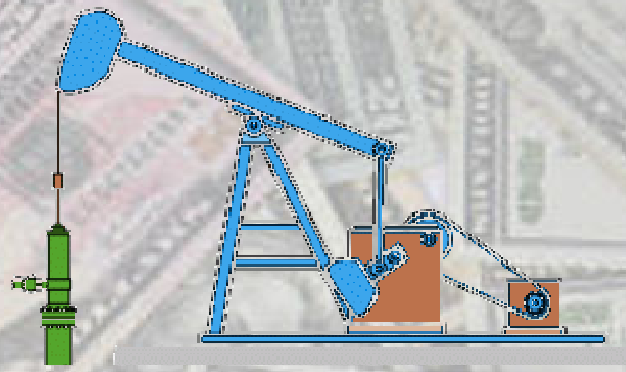


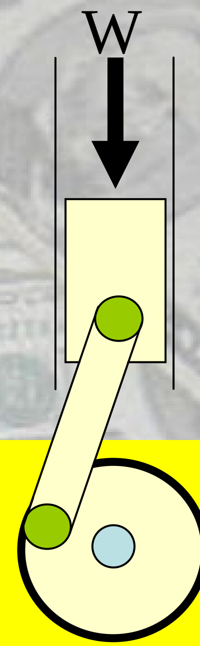
Braking Profile (Rectangular)

Cyclic Load Type

Definition

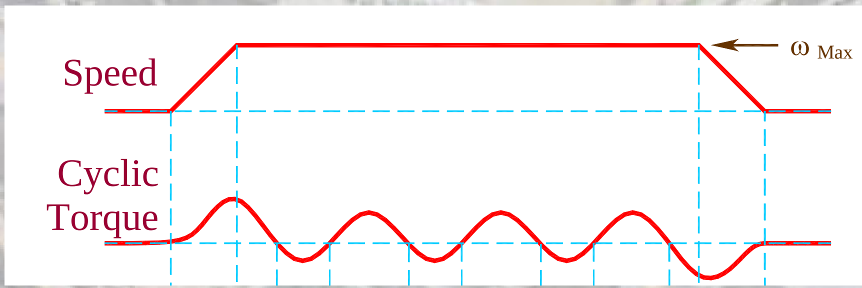
- *A load that exhibits cyclic variations in torque while running at constant speed*





Examples

- *Eccentric Drives*
- *Stamping Presses*
- *Punch Presses*
- *Pump Jacks*
- *Washing Machines*
- *Mechanical Indexers*

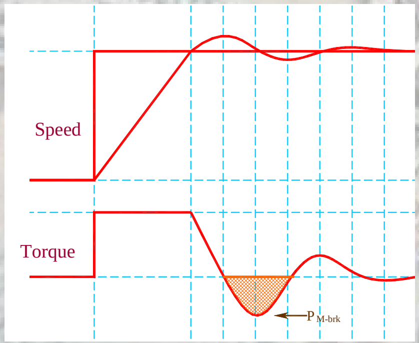


Definition

- *An effect where the motor speed exceeds the speed target during very rapid acceleration*

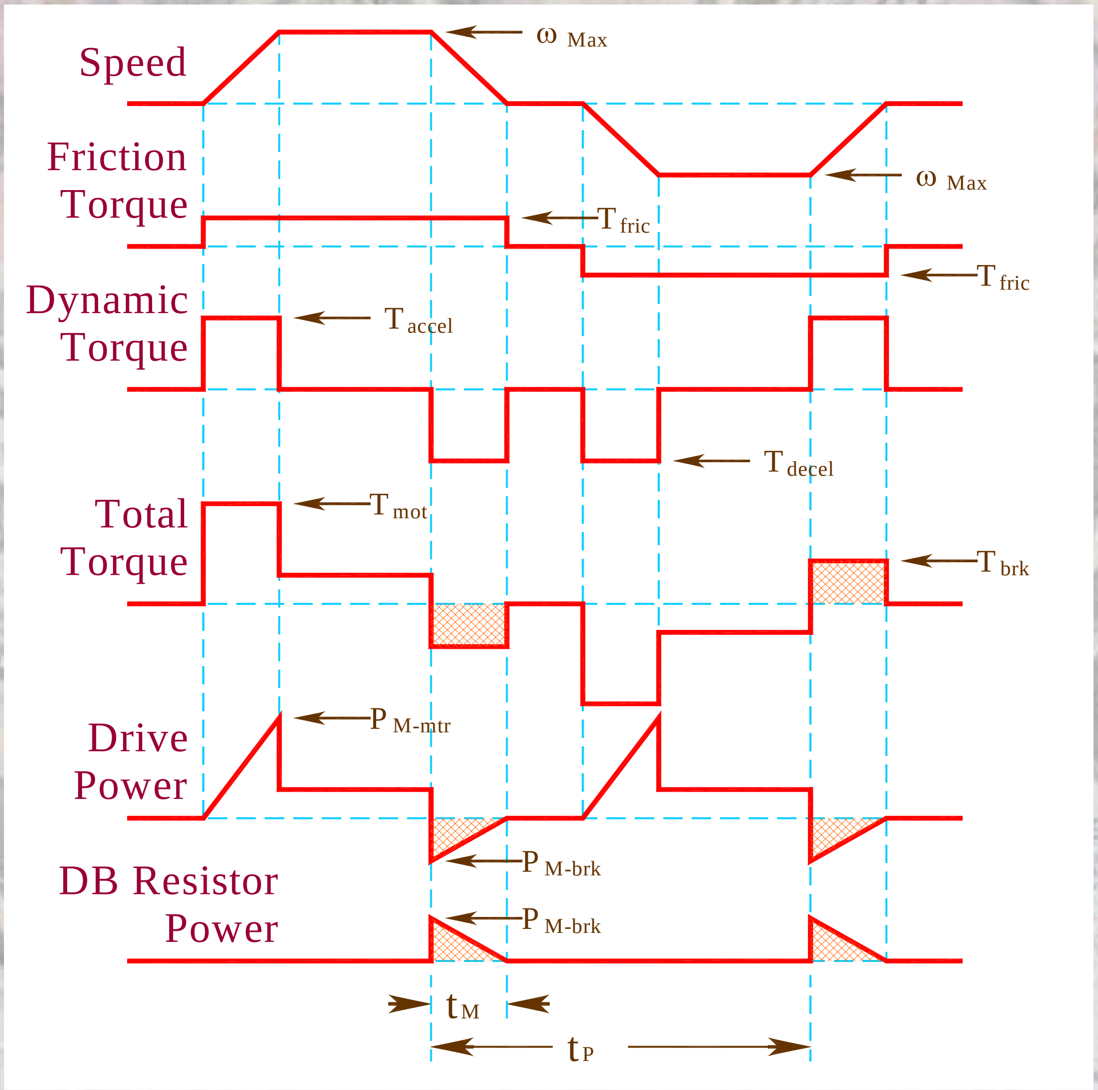
Examples

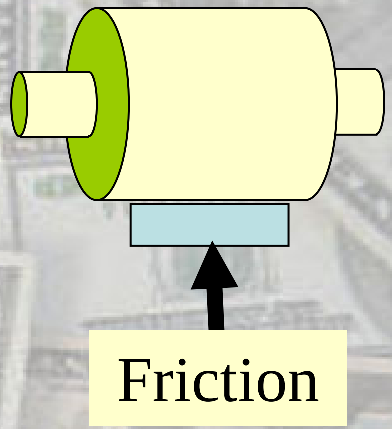
- *High Performance Indexing*
- *Very Large Inertia in Closed-Loop Systems*



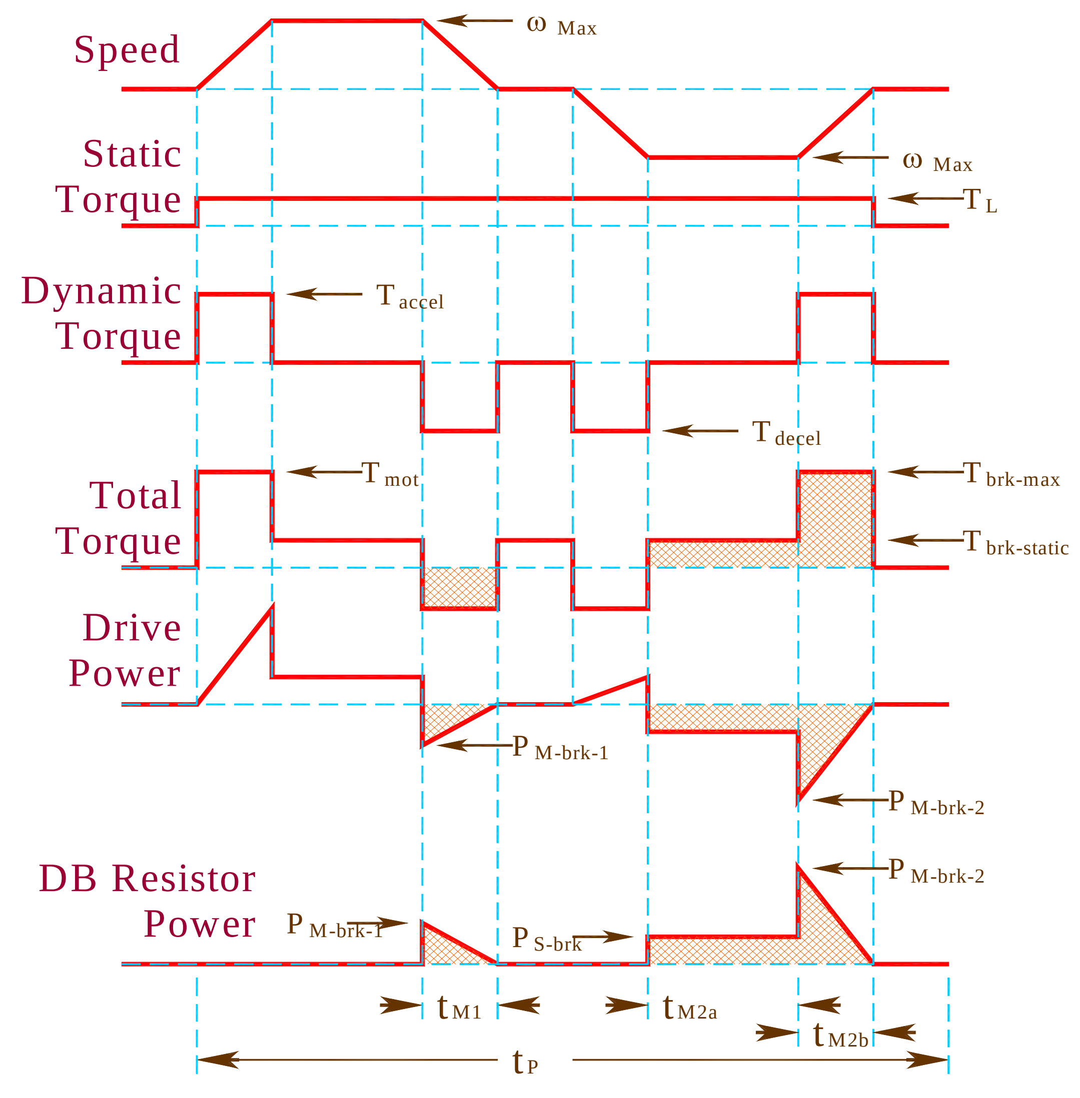
The VFD exerts braking torque to bring the motor back to target speed.

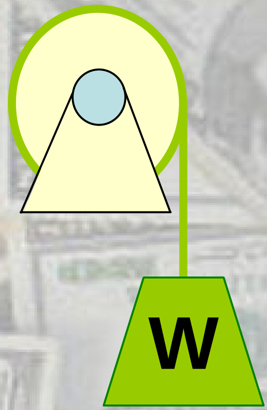
Inertial Load + Friction





Static Load + Inertia

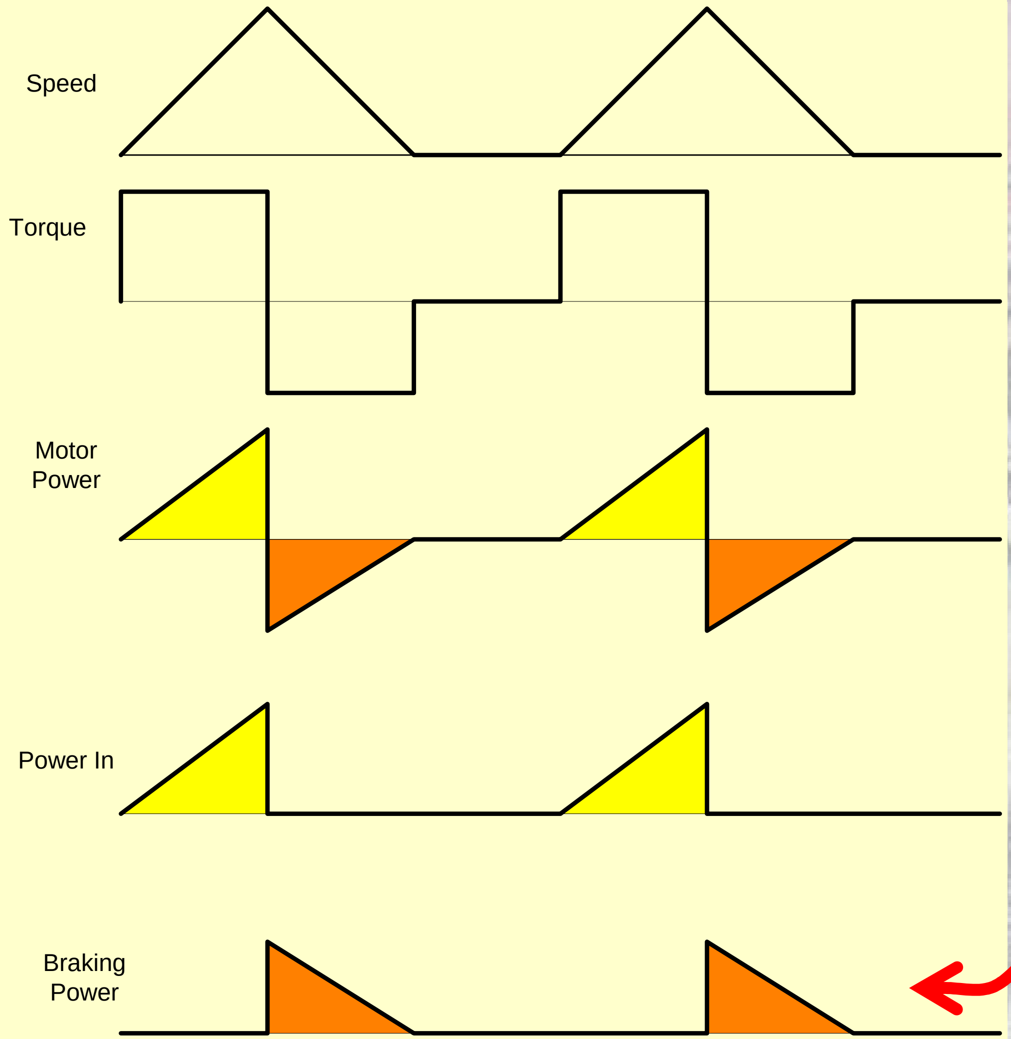




Note:
Heavy Duty Braking

Equivalent Duty is not Duty Cycle

Aggressive Indexing Application



ED		
Input	**Brake**	**Motor**
%	**%**	**%**
16.7%	**16.7%**	**33.3%**

$$\text{Duty Cycle} = \frac{\text{On - Time}}{\text{Cycle Time}}$$

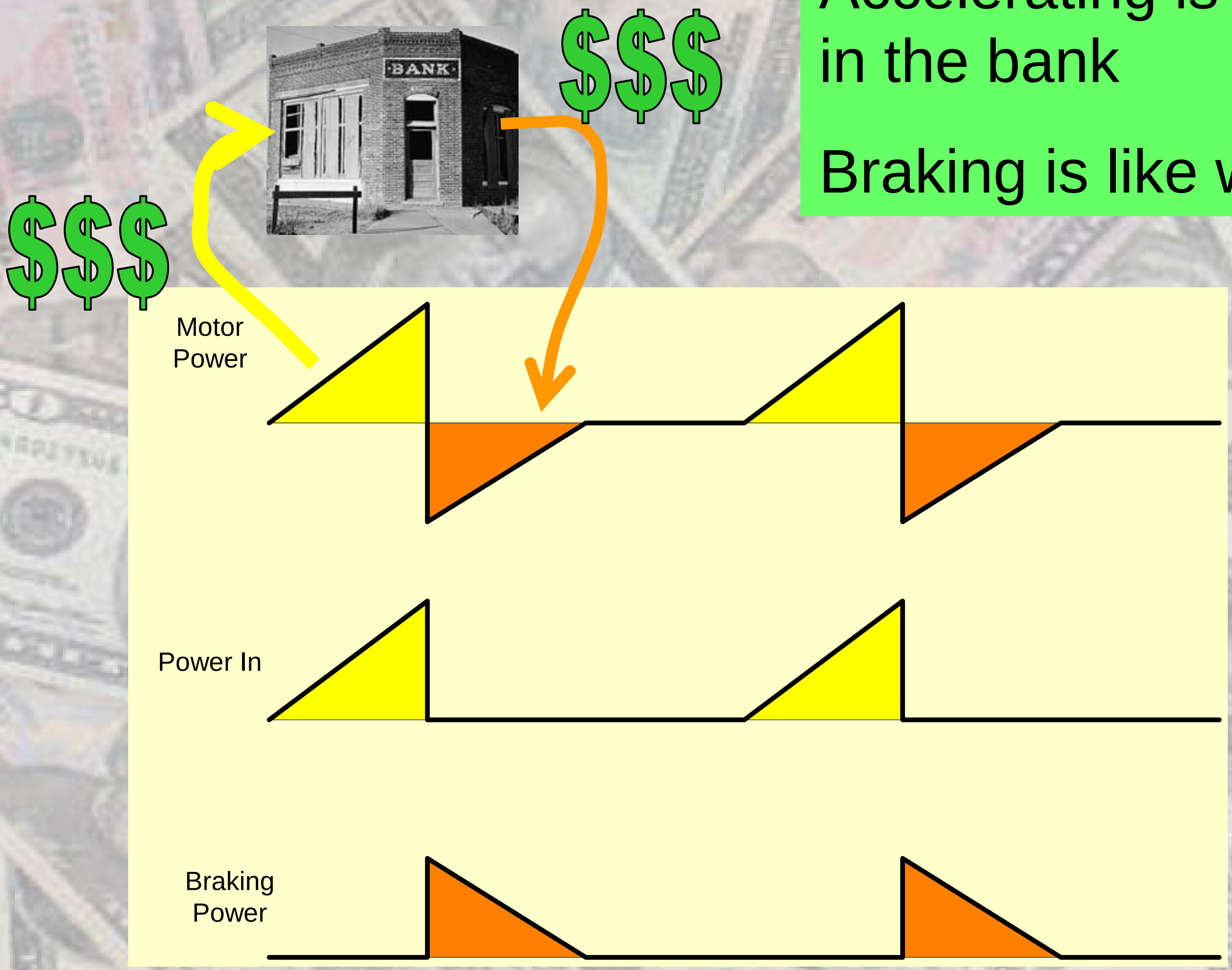
Duty Cycle = 33%
ED = 16.7%

1/2 of 1/3 = 16.7%

Where the Money Goes

Accelerating is like putting money in the bank

Braking is like withdrawing it.



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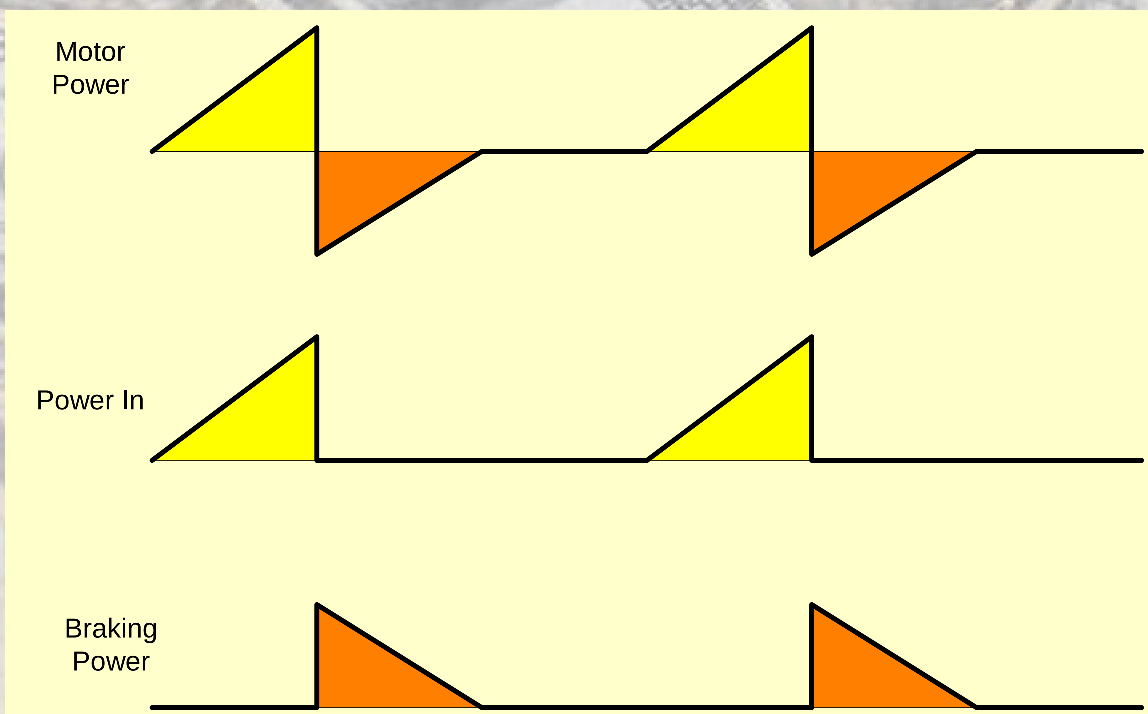
Cost Savings

			Output		ED				Hourly				Daily				Yearly		
Output		Eff	Input	Brake	Input	Brake	Motor	Cost	Input	Brake	Hours per Day		Input	Brake	Days per Year		Input	Brake	Net
hp	kw	%	kw	kw	%	%	%	$/kwh	$/hr	$/hr	hr/shift	Shft/day	$/day	$/day	days/wk	weeks/yr	$/yr	$/yr	$/yr
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	1	$8.38	$7.56	5	50	$2,094	$1,890	$204
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	2	$16.75	$15.12	5	50	$4,188	$3,780	$408
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	5	50	$6,282	$5,670	$613
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	6	50	$7,539	$6,804	$735
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	7	52	$9,147	$8,255	$892



Cost to operate without recovering braking energy

Cost to operate with recovering braking energy

Conversion Factors

1 kwh = 3,600,000 watt·seconds = 3,600,000 Joules

Determining the Required Braking

- *The **application** and the **load profile** determine the amount of **recoverable** braking energy.*
- *The **time in service** and utility **cost per kwh** determine what the **cost savings** with line regeneration will be.*

Two Approaches

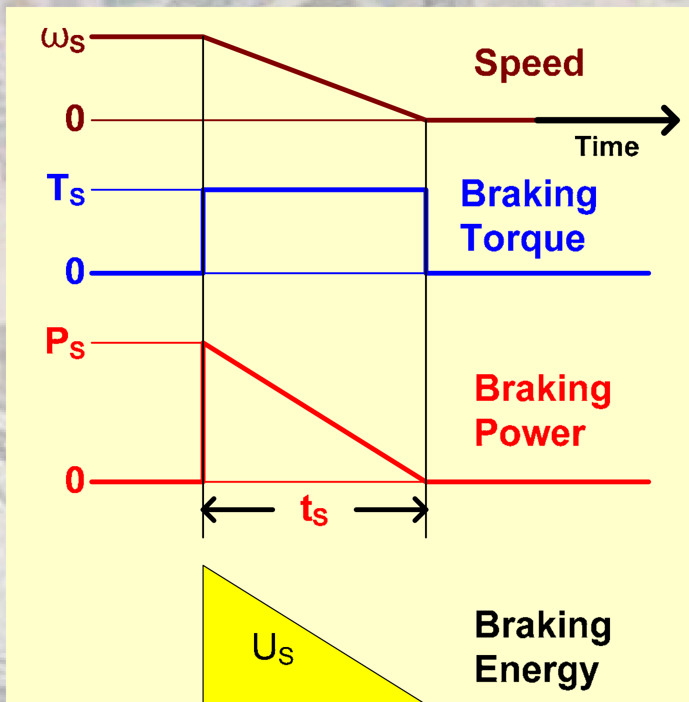
ED Approach

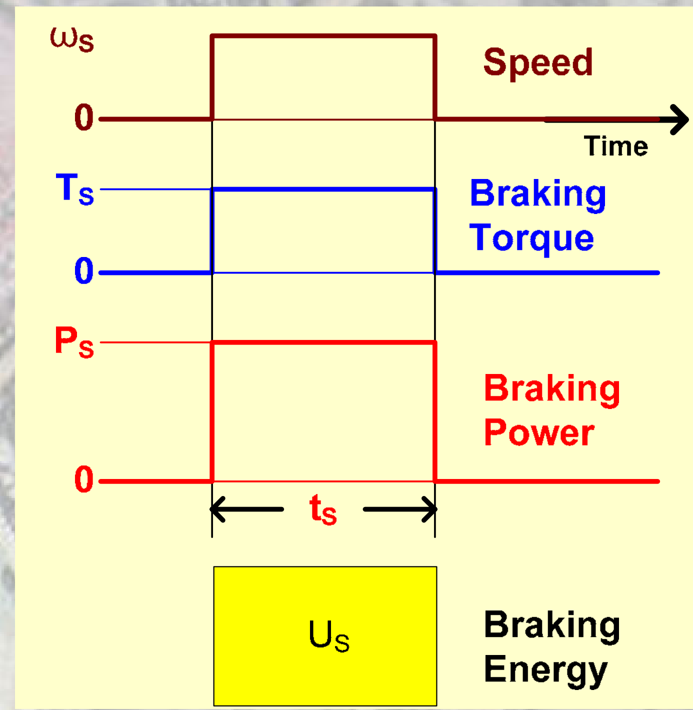
Cost of Stopping = Motor kw * Brake ED * Service Hours/Year * Rate per kwh

Cost per Stop Approach

Cost of Stopping = Cost per Stop * Number of Stops per Year

Rough Estimate





$$U_{Stop} = \int Power_{Stop} \cdot dt = \frac{1}{2} P_S t_S$$

$$U_{Stop} = \int Power_{Stop} \cdot dt = P_S t_S$$

Example – Huge Inertia

A **100HP** takes **2 minutes** at **100% torque** to stop a huge inertial load.

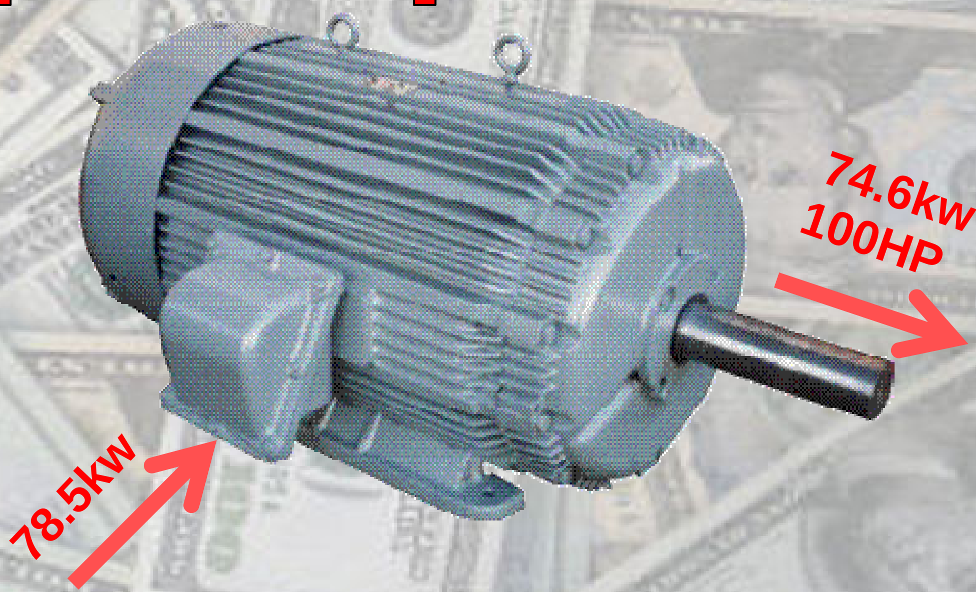
Energy per Stop $U_{Stop} = 0.5 \cdot 100hp \cdot 746 \cdot 120s = 4{,}476{,}000$ Joules = 1.24 kwh

The cost per stop at $0.08/kwh is about $0.10/stop.

$0.10 per Stop

Remember

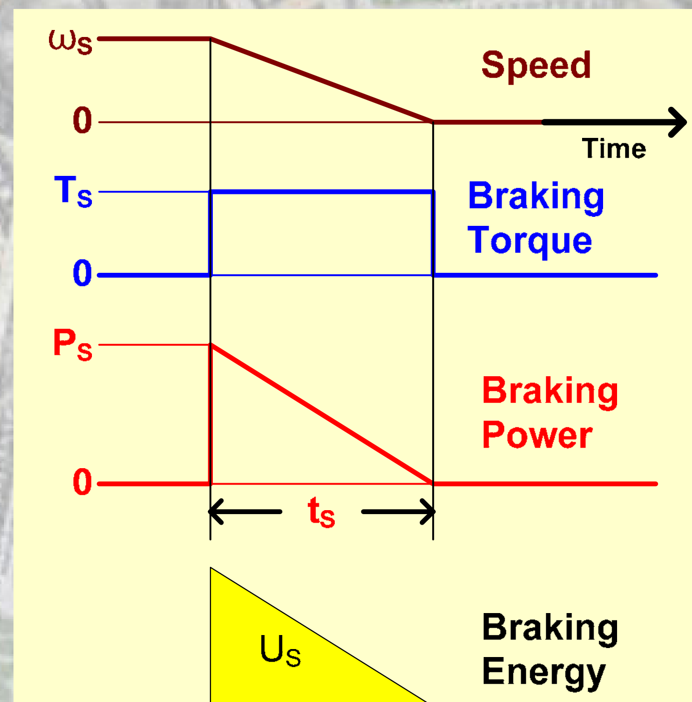
1 HP = 746 w
= 0.746 kw



Inertial Load Stopping

Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	120	0.50	1.181	$0.08	$0.094	10	$0.94	8	1	$7.56	5	50	$1,890
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	10	$0.16	8	1	$1.26	5	50	$315
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	1	$0.63	5	50	$157
100	74.6	95%	70.87	5	0.50	0.049	$0.08	$0.004	10	$0.04	8	1	$0.31	5	50	$79
100	74.6	95%	70.87	2	0.50	0.020	$0.08	$0.002	10	$0.02	8	1	$0.13	5	50	$31

The larger the inertia, the more the savings.



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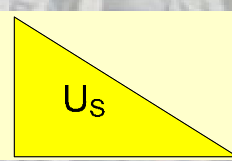
Cost Recovery Comparison

Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	120	0.50	1.181	$0.08	$0.094	10	$0.94	8	1	$7.56	5	50	$1,890
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	10	$0.16	8	1	$1.26	5	50	$315
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	1	$0.63	5	50	$157
100	74.6	95%	70.87	5	0.50	0.049	$0.08	$0.004	10	$0.04	8	1	$0.31	5	50	$79
100	74.6	95%	70.87	2	0.50	0.020	$0.08	$0.002	10	$0.02	8	1	$0.13	5	50	$31

Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	6	$0.09	8	1	$0.76	5	50	$189
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	10	$0.16	8	1	$1.26	5	50	$315
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	20	$0.31	8	1	$2.52	5	50	$630
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	30	$0.47	8	1	$3.78	5	50	$945
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	60	$0.94	8	1	$7.56	5	50	$1,890

The more you stop, the more you save.



Braking Energy

ED vs Cost/Stop

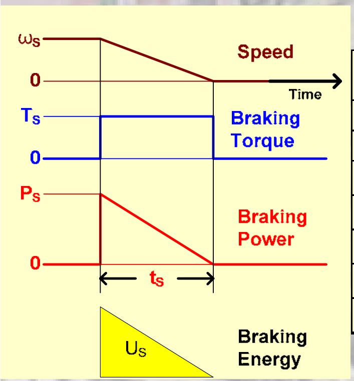
Motor									Cost to Operate										
			Output		ED				Hourly				Daily				Yearly		
Output		Eff	Input	Brake	Input	Brake	Motor	Cost	Input	Brake	Hours per Day		Input	Brake	Days per Year		Input	Brake	Net
hp	kw	%	kw	kw	%	%	%	$/kwh	$/hr	$/hr	hr/shift	Shft/day	$/day	$/day	days/wk	weeks/yr	$/yr	$/yr	$/yr
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	1	$8.38	$7.56	5	50	$2,094	$1,890	$204
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	2	$16.75	$15.12	5	50	$4,188	$3,780	$408
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	5	50	$6,282	$5,670	$613
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	6	50	$7,539	$6,804	$735
100	74.6	95%	78.53	70.87	16.7%	16.7%	33.3%	$0.08	$1.05	$0.94	8	3	$25.13	$22.68	7	52	$9,147	$8,255	$892

Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	6	$0.09	8	1	$0.76	5	50	$189
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	10	$0.16	8	1	$1.26	5	50	$315
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	20	$0.31	8	1	$2.52	5	50	$630
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	30	$0.47	8	1	$3.78	5	50	$945
100	74.6	95%	70.87	20	0.50	0.197	$0.08	$0.016	60	$0.94	8	1	$7.56	5	50	$1,890

Both methods arrive at the **same answer** given the **same conditions**.

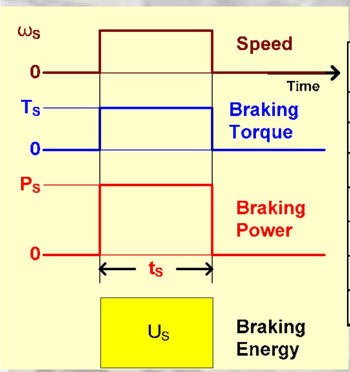
Load Comparison

Large Inertial Load stopping every 6 minutes



Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	1	$0.63	5	50	$157
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	2	$1.26	5	50	$315
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	3	$1.89	5	50	$472
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	3	$1.89	6	50	$567
100	74.6	95%	70.87	10	0.50	0.098	$0.08	$0.008	10	$0.08	8	3	$1.89	7	52	$688

One 10-second Lift (lower) every 6 minutes

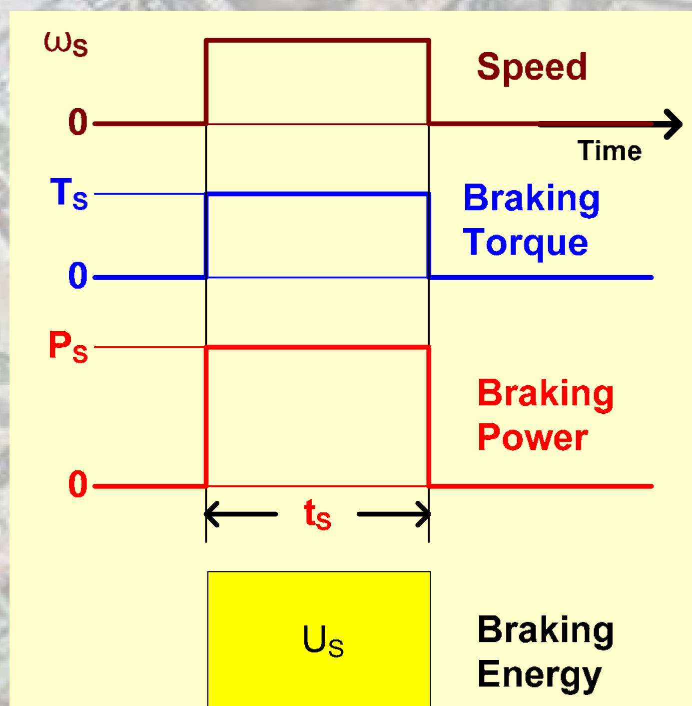


Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	10	1.00	0.197	$0.08	$0.016	10	$0.16	8	1	$1.26	5	50	$315
100	74.6	95%	70.87	10	1.00	0.197	$0.08	$0.016	10	$0.16	8	2	$2.52	5	50	$630
100	74.6	95%	70.87	10	1.00	0.197	$0.08	$0.016	10	$0.16	8	3	$3.78	5	50	$945
100	74.6	95%	70.87	10	1.00	0.197	$0.08	$0.016	10	$0.16	8	3	$3.78	6	50	$1,134
100	74.6	95%	70.87	10	1.00	0.197	$0.08	$0.016	10	$0.16	8	3	$3.78	7	52	$1,376

Usage

Medium Duty Lifter

Motor				Cost/Stop					Cost Recovery							
Output		Eff	Brake	Stop Time	Profile		Cost			Hourly	Hours per Day		Daily	Days per Year		Yearly
hp	kw	%	kw	seconds		kwh/stop	$/kwh	$/stop	stops/hr	$/hr	hr/shift	Shft/day	$/day	days/wk	weeks/yr	$/yr
100	74.6	95%	70.87	15	1.00	0.295	$0.08	$0.024	20	$0.47	8	1	$3.78	5	50	$945
100	74.6	95%	70.87	15	1.00	0.295	$0.08	$0.024	20	$0.47	8	2	$7.56	5	50	$1,890
100	74.6	95%	70.87	15	1.00	0.295	$0.08	$0.024	20	$0.47	8	3	$11.34	5	50	$2,835
100	74.6	95%	70.87	15	1.00	0.295	$0.08	$0.024	20	$0.47	8	3	$11.34	6	50	$3,402
100	74.6	95%	70.87	15	1.00	0.295	$0.08	$0.024	20	$0.47	8	3	$11.34	7	52	$4,127

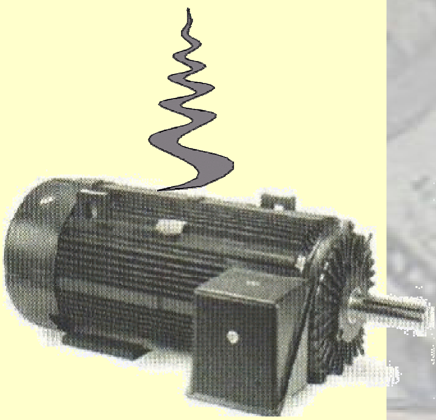


Regeneration Choices

- *What to do with recoverable energy*
  - ***Use it***
    - *Common DC Bus*
    - *Line Regeneration*
  - ***Store it***
    - *Mechanical Inertia*
    - *Capacitor Bank, Batteries*
  - ***Waste it***
    - *In the motor*
    - *In Dynamic Braking Resistors*

■ *Burn it off in the motor*

- *High Slip Braking*
- *High Flux Braking*
- *Best for non-repetitive stopping*
- *Little control of deceleration rate*



■ *Burn it off in DB Resistors*

- *Most Common solution*
- *Economical even for repetitive stopping, indexing, general braking*
- ***Full control** of speed, torque during deceleration*

In Mechanical Inertia

- *Internal OV Suppression*
- *Vector Control Regen Torque Limit*
- ***Over-Voltage Suppression Software***
- *Kinetic Energy Braking*

In Bus Capacitors

- *Power Loss Ride-Through*
- *External Bank*

In Battery Bank

Alessandro Volta's Battery

- ***Transfer it through Common DC Bus***
  - *Input-Absorber*
  - *Multiple Drives on a Common Rectifier*
  - ***Most economical way to deal with regeneration***
- ***Transfer it through Line Regeneration***
  - *RC5 = anti-rectifier (6-pulse conversion)*
  - *DC5 = bi-directional converter (PWM)*
  - *AC7 = direct AC-AC converter*

Useful Application Formulas

DB Threshold Voltage (760VDC on 480V units)

$$R_{DB} \leq \frac{V^2_{Thres}}{\text{Required Peak Braking Power}}$$

Drive OV (over voltage) trip level

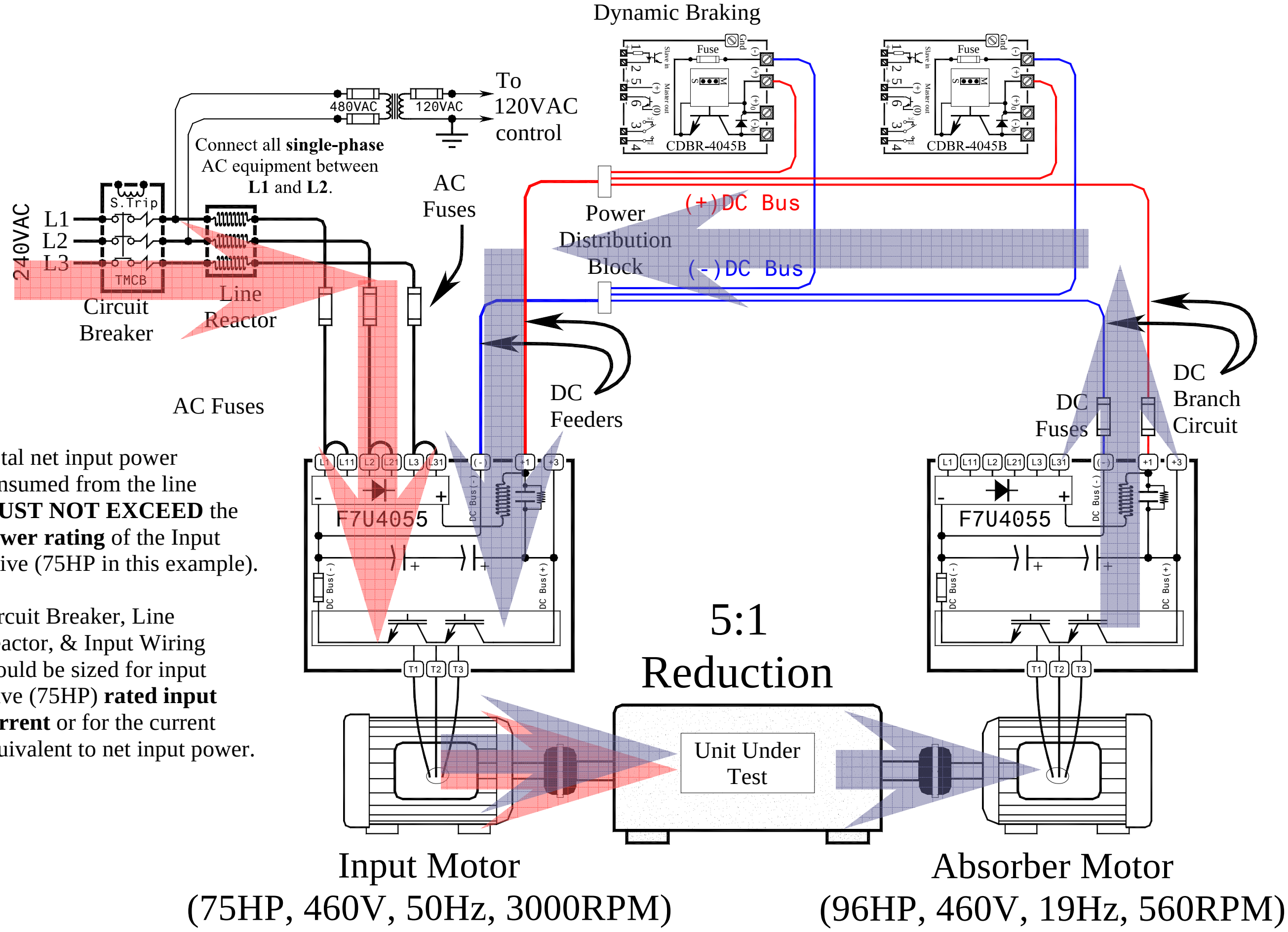
$$R_{DB} \geq \frac{V_{OV}}{I_{CDBR\ (Max)}}$$

$$\frac{\text{Required Average Braking Power}}{I^2_{RMS\ (Max\ Allowed)}} \leq R_{DB}$$

Larger of DB unit max rms current and Resistor max rms current

Power Flow Around Dyne

Common Bus Power Connections
75-75 HP 480V Transmission Dynamometer

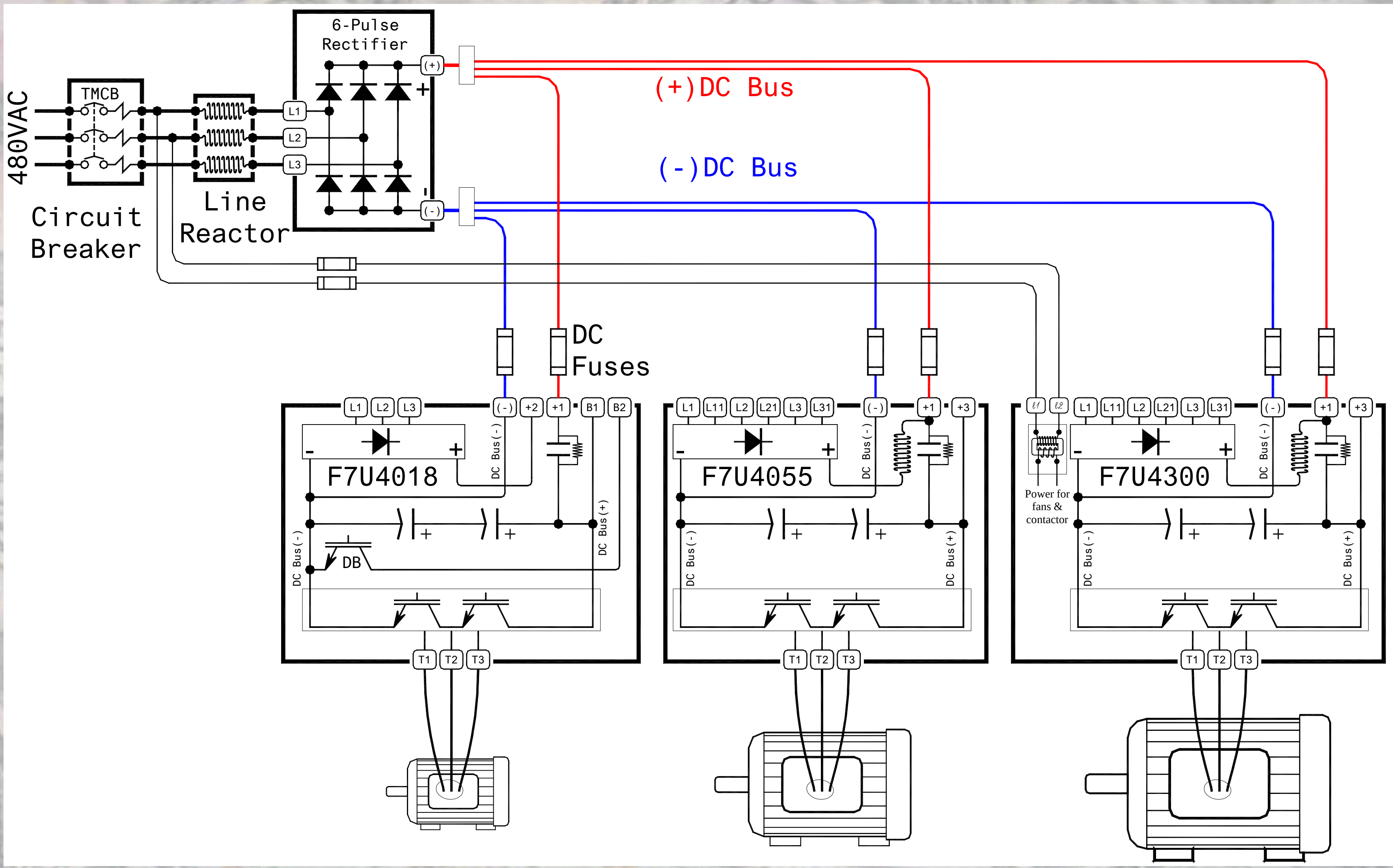


Total net input power consumed from the line **MUST NOT EXCEED** the **power rating** of the Input Drive (75HP in this example).

Circuit Breaker, Line Reactor, & Input Wiring should be sized for input drive (75HP) **rated input current** or for the current equivalent to net input power.

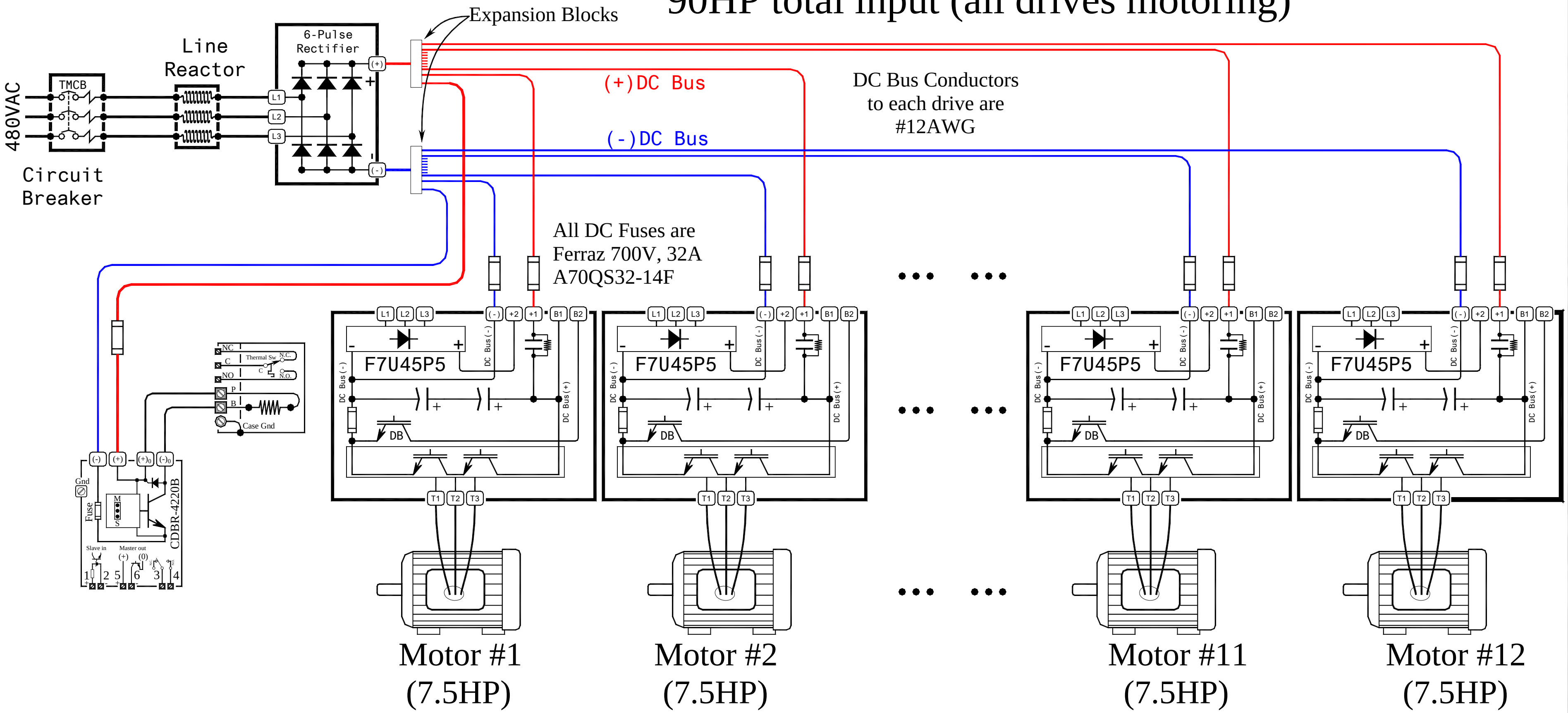
This is Preliminary Documentation. Any suggestions, comments, corrections -- contact Joe Pottebaum (Industrial Applications) at Ex 2304 or email joseph_pottebaum@yaskawa.com.
75-75 HP 230V Input-Absorber w Common DB 2005-09-14

Common Bus – Dissimilar VFD's



Extreme Example – 12 Drives

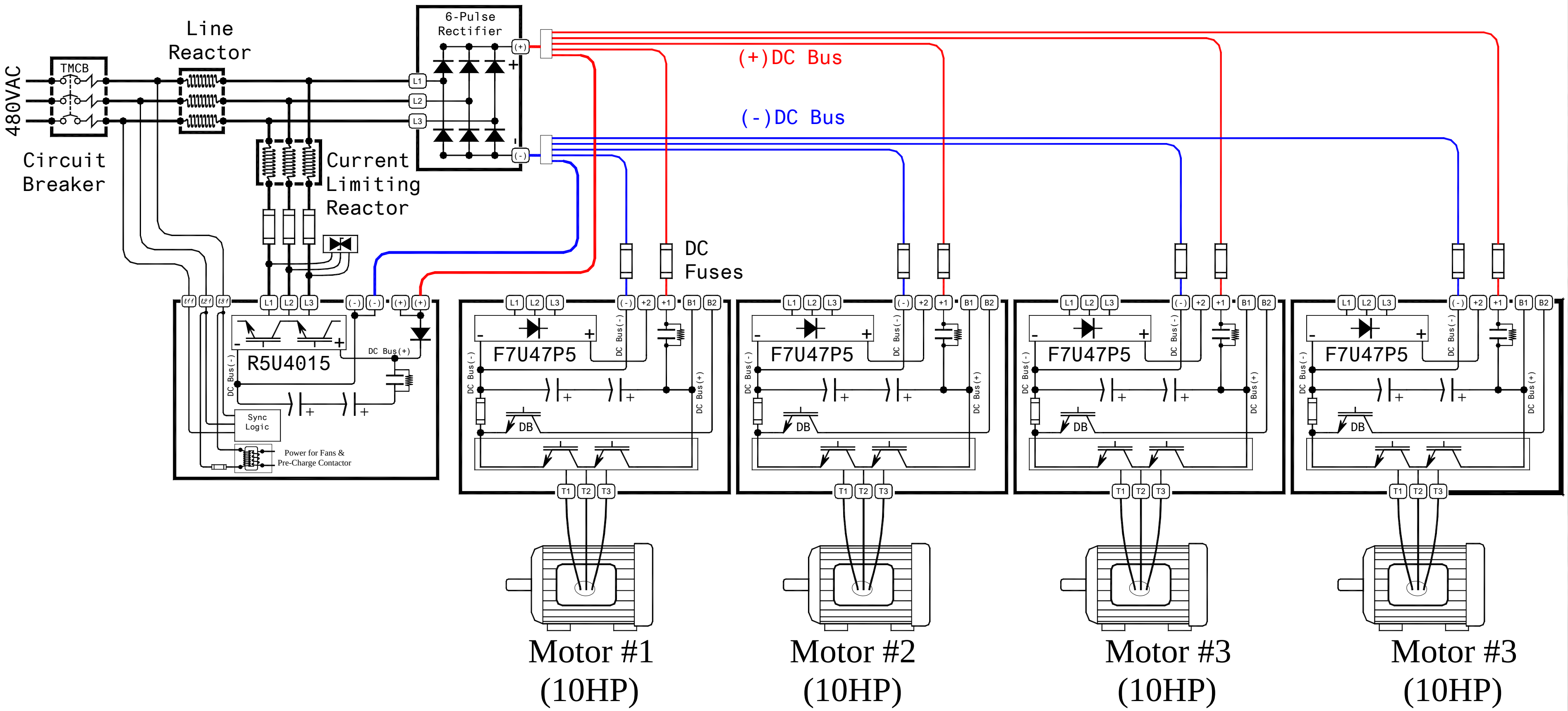
Common Bus Power Connections
Twelve 7.5HP Drives with Common Rectifier and DB
90HP total input (all drives motoring)



This is Preliminary Documentation. Any suggestions, comments, corrections -- contact
Joe Pottebaum (Industrial Applications) at Ex 2304 or email joseph_pottebaum@yaskawa.com.
Four 10HP in Common Rectifier w DB 2006-05-17

Common Bus with Line Regen

Common Bus Power Connections
Four 10HP in Common Rectifier Configuration with 20HP RC5



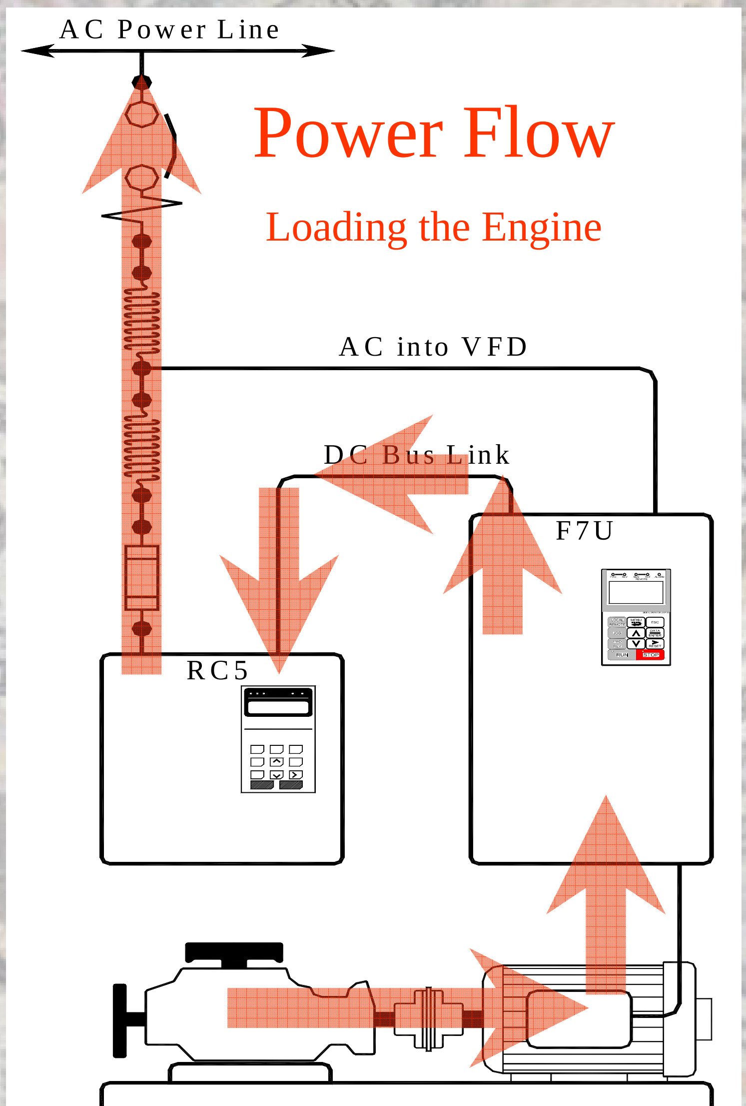
This is Preliminary Documentation. Any suggestions, comments, corrections -- contact
Joe Pottebaum (Industrial Applications) at Ex 2304 or email joseph_pottebaum@yaskawa.com.
Four 10HP in Common Rectifier w 20HP RC5 2006-05-17

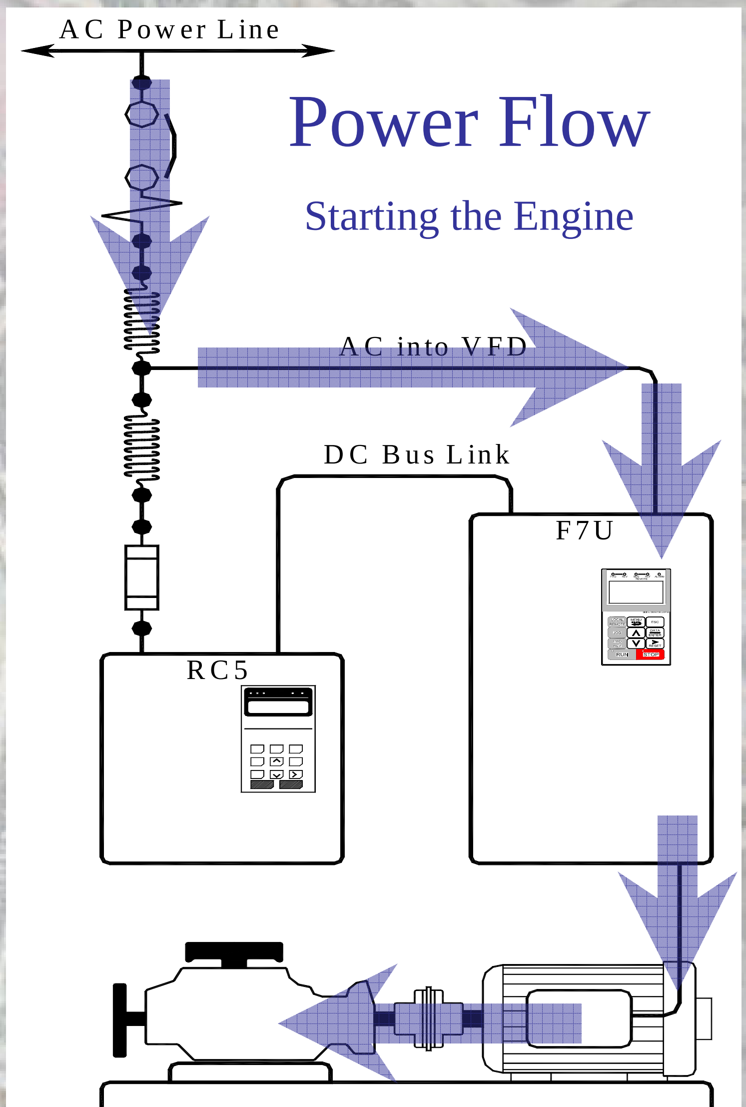
General Rules for Common DC Bus

- *All VFD's with a common DC bus* ***must power up simultaneously***
  - *(soft-charge limitations).*
- *Use* ***[+1]*** *and* ***[-]*** *terminals for DC bus connections.*
  - *Each VFD may only soft-charge its own capacitor bank.*
- *All branch circuits must be protected.*
  - *DC Bus fuses*
- *Total power into a VFD's AC input must not exceed the* ***power rating*** *of the VFD.*

Yaskawa Training Cafe

Line Regeneration





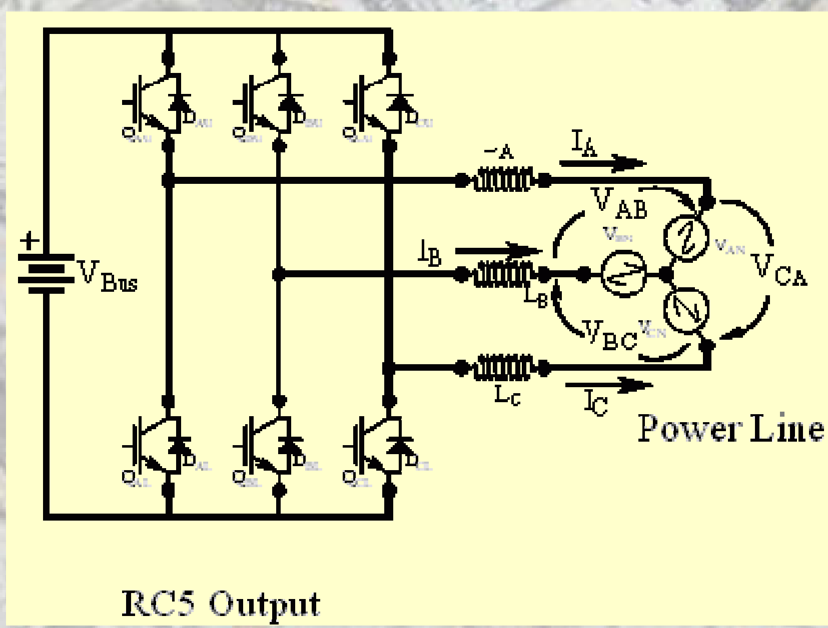
RC5 or DB?

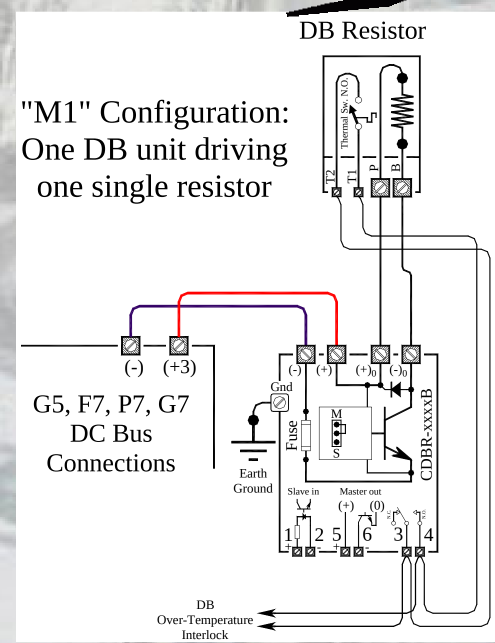

YASKAWA
VARISPEED
656RC5
DIGITAL OPERATOR
JVOP 130U
LOCAL REMOTE
MENU
ESC
JOG
DATA ENTER
FWD REV
RESET
RUN
STOP


BRAKING UNIT

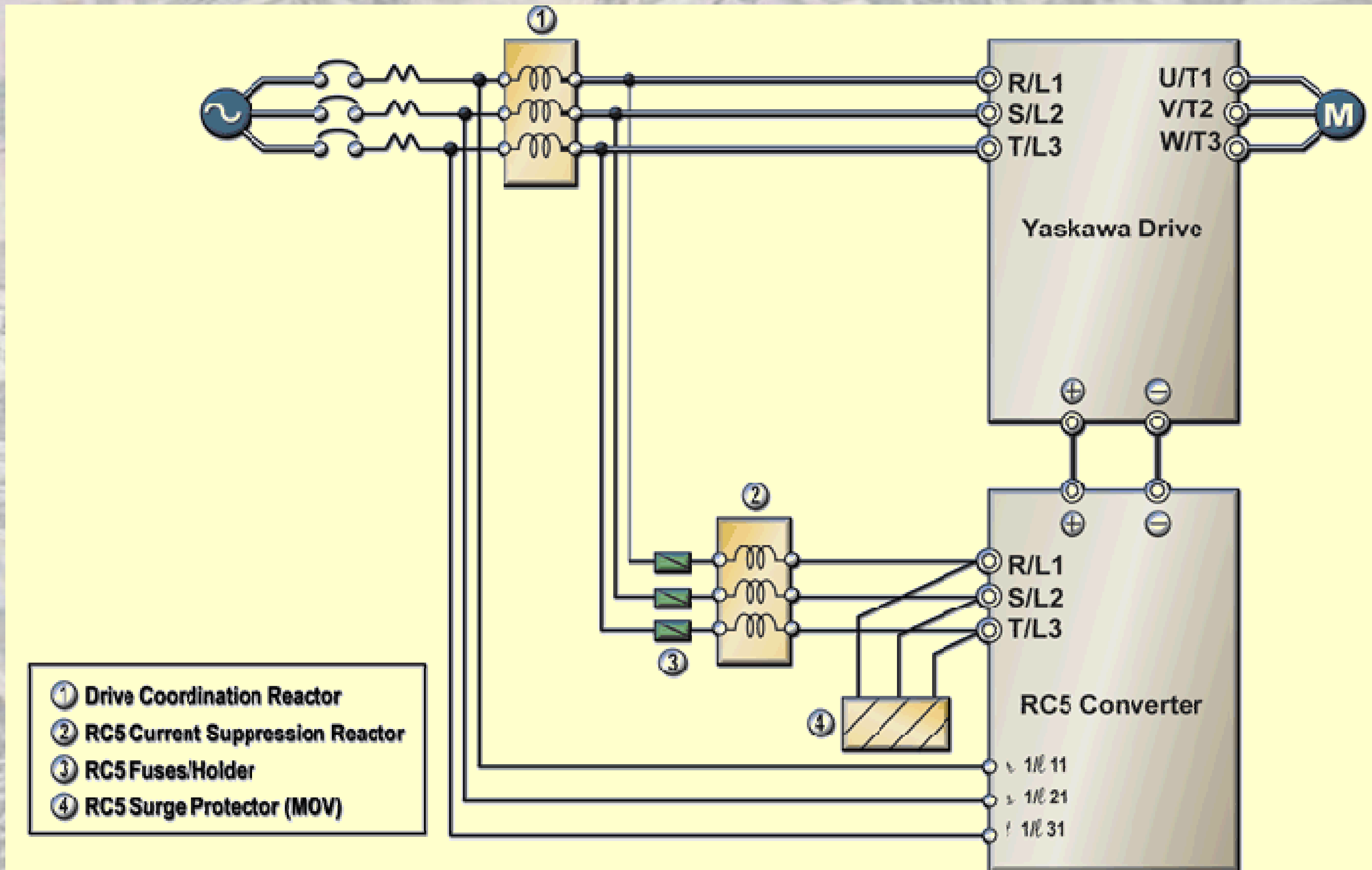
RC5 or DB

- ***RC5** transfers energy from the drive's DC bus to the AC line.*
- ***Dynamic Braking** transfers energy to the air as **heat**.*





RC5 Component Interconnection



Take the Lid Off

Small RC5 – R5U43P7
(5HP)

RC5 from Price Book

Basic RC5 - Standard Duty - 25% Duty Cycle, 60 Seconds on-time					
Rated Input Voltage	Drive Nominal HP (1)	Regenerative Kit Part Number (2)	Model Number of RC5 Used in Kit CIMR-R5U*	Standard Enclosure	Complete Kit List Price (2)
230V	5	RC5-230-5HP-SD	**23P71A**	NEMA 1	**1889**
230V	7.5	RC5-230-7.5HP-SD	**25P51A**	NEMA 1	**2058**
230V	10	RC5-230-10HP-SD	**27P51A**	NEMA 1	**2309**
230V	15	RC5-230-15HP-SD	**20111A**	NEMA 1	**2697**
230V	20	RC5-230-20HP-SD	**20151A**	NEMA 1	**3180**
230V	25	RC5-230-25HP-SD	**20181A**	NEMA 1	**4241**
230V	30	RC5-230-30HP-SD	**20221A**	NEMA 1	**4602**
230V	40	RC5-230-40HP-SD	**20301A**	NEMA 1	**5253**
230V	50	RC5-230-50HP-SD	**20370A**	Protected Chassis	**7129**
460V	5	RC5-460-5HP-SD	**43P71A**	NEMA 1	**2031**
460V	7.5	RC5-460-7.5HP-SD	**45P51A**	NEMA 1	**2307**
460V	10	RC5-460-10HP-SD	**47P51A**	NEMA 1	**2512**
460V	15	RC5-460-15HP-SD	**40111A**	NEMA 1	**2729**
460V	20	RC5-460-20HP-SD	**40151A**	NEMA 1	**3031**
460V	25	RC5-460-25HP-SD	**40181A**	NEMA 1	**3891**
460V	30	RC5-460-30HP-SD	**40221A**	NEMA 1	**4478**
460V	40	RC5-460-40HP-SD	**40301A**	NEMA 1	**4960**
460V	50	RC5-460-50HP-SD	**40370A**	Protected Chassis	**6863**
460V	60	RC5-460-60HP-SD	**40450A**	Protected Chassis	**7374**
460V	75	RC5-460-75HP-SD	**40550A**	Protected Chassis	**8547**
460V	100	RC5-460-100HP-SD	**40750A**	Protected Chassis	**11,160**

480V Dynamic Braking

5 HP	Continuous	1 of CDBR-4045B with 1 of URS000157	M1S2	9.97 HP =	199%	6.11 HP =	122%	Cont	inuous	**$1,623**
7.5 HP	Continuous	1 of CDBR-4045B with 1 of URS000155	M1S2	15.5 HP =	206%	7.93 HP =	106%	Cont	inuous	**$1,901**
7.5 HP	Heavy	1 of CDBR-4045B with 1 of URS000153	M1S2	15.5 HP =	206%	3.88 HP =	52%	521 KJ =	698 HP-sec	**$1,367**
10 HP	Continuous	1 of CDBR-4045B with 1 of URS000151 and 1 of URS000150	M1XS3	15.5 HP =	155%	11.5 HP =	115%	Cont	inuous	**$2,315**
10 HP	Heavy	1 of CDBR-4045B with 1 of URS000155	M1S2	15.4 HP =	154%	7.89 HP =	79%	1448 KJ =	1941 HP-sec	**$1,901**
15 HP	Continuous	1 of CDBR-4045B with 1 of URS000137 and 1 of URS000136	M1XS3	26.4 HP =	176%	14.7 HP =	98%	Cont	inuous	**$2,368**
15 HP	Heavy	1 of CDBR-4045B with 1 of URS000151	M1S2	23.1 HP =	154%	7.60 HP =	51%	941 KJ =	1261 HP-sec	**$1,736**
20 HP	Continuous	2 of CDBR-4045B with 2 of URS000151 and 2 of URS000150	M2XS3	30.7 HP =	153%	22.7 HP =	113%	Cont	inuous	**$4,630**
20 HP	Heavy	1 of CDBR-4045B with 1 of URS000143	M1S2	30.5 HP =	152%	9.99 HP =	50%	1400 KJ =	1877 HP-sec	**$1,912**
25 HP	Continuous	2 of CDBR-4045B with 3 of URS000143	M2S3	40.5 HP =	162%	29.9 HP =	119%	Cont	inuous	**$4,986**
25 HP	Heavy	2 of CDBR-4045B with 2 of URS000151	M2S2	45.9 HP =	183%	15.1 HP =	60%	2036 KJ =	2729 HP-sec	**$3,472**
30 HP	Continuous	1 of CDBR-4220B with 2 of URS000118	M1S4	49.0 HP =	163%	31.0 HP =	103%	Cont	inuous	**$4,967**
30 HP	Heavy	2 of CDBR-4045B with 2 of URS000151	M2S2	45.7 HP =	152%	15.0 HP =	50%	1841 KJ =	2468 HP-sec	**$3,472**
30 HP	Medium	2 of CDBR-4045B with 2 of URS000149	M2S2	45.7 HP =	152%	7.42 HP =	25%	775 KJ =	1039 HP-sec	**$2,734**
30 HP	Standard	1 of CDBR-4045B with 1 of URS000150	M1	45.7 HP =	152%	3.76 HP =	13%	352 KJ =	472 HP-sec	**$1,329**
30 HP	Decel	1 of CDBR-4045B with 1 of URS000148	M1	45.7 HP =	152%	1.85 HP =	6%	174 KJ =	233 HP-sec	**$1,119**
40 HP	Continuous	1 of CDBR-4220B with 1 of URS000121	M1S3	65.0 HP =	163%	44.7 HP =	112%	Cont	inuous	**$4,703**
40 HP	Heavy	2 of CDBR-4045B with 2 of URS000143	M2S2	60.3 HP =	151%	19.8 HP =	49%	2713 KJ =	3637 HP-sec	**$3,824**
40 HP	Medium	2 of CDBR-4045B with 2 of URS000141	M2S2	60.3 HP =	151%	9.34 HP =	23%	646 KJ =	866 HP-sec	**$2,960**
40 HP	Standard	1 of CDBR-4045B with 1 of URS000142	M1	60.3 HP =	151%	4.94 HP =	12%	522 KJ =	700 HP-sec	**$1,378**
40 HP	Decel	1 of CDBR-4045B with 1 of URS000140	M1	60.3 HP =	151%	2.34 HP =	6%	146 KJ =	196 HP-sec	**$1,186**
50 HP	Continuous	1 of CDBR-4220B with 1 of URS000167	M1S3	85.1 HP =	170%	55.6 HP =	111%	Cont	inuous	**$7,668**
50 HP	Heavy	1 of CDBR-4220B with 1 of URS000120	M1S2	97.2 HP =	194%	29.7 HP =	59%	3455 KJ =	4631 HP-sec	**$4,703**
50 HP	Medium	1 of CDBR-4220B with 1 of URS000118	M1S2	97.2 HP =	194%	15.4 HP =	31%	1093 KJ =	1465 HP-sec	**$3,526**
50 HP	Standard	2 of CDBR-4045B with 1 of URS000151	M2	90.8 HP =	182%	7.45 HP =	15%	709 KJ =	950 HP-sec	**$2,486**
50 HP	Decel	2 of CDBR-4045B with 1 of URS000149	M2	90.8 HP =	182%	3.68 HP =	7%	348 KJ =	466 HP-sec	**$2,117**
60 HP	Continuous	1 of CDBR-4220B with 1 of URS000169	M1S2	116 HP =	194%	60.1 HP =	100%	Cont	inuous	**$7,604**
60 HP	Heavy	1 of CDBR-4220B with 1 of URS000120	M1S2	97.0 HP =	162%	29.6 HP =	49%	3102 KJ =	4158 HP-sec	**$4,703**
60 HP	Medium	1 of CDBR-4220B with 1 of URS000118	M1S2	97.0 HP =	162%	15.4 HP =	26%	1048 KJ =	1405 HP-sec	**$3,526**
60 HP	Standard	2 of CDBR-4045B with 1 of URS000151	M2	90.5 HP =	151%	7.43 HP =	12%	695 KJ =	932 HP-sec	**$2,486**
60 HP	Decel	2 of CDBR-4045B with 1 of URS000149	M2	90.5 HP =	151%	3.67 HP =	6%	343 KJ =	460 HP-sec	**$2,117**
75 HP	Continuous	2 of CDBR-4220B with 2 of URS000121	M2S3	129 HP =	172%	88.5 HP =	118%	Cont	inuous	**$9,406**
75 HP	Heavy	1 of CDBR-4220B with 1 of URS000166	M1S2	127 HP =	169%	36.8 HP =	49%	3595 KJ =	4819 HP-sec	**$6,035**
75 HP	Medium	1 of CDBR-4220B with 1 of URS000163	M1S2	127 HP =	169%	19.0 HP =	25%	2185 KJ =	2929 HP-sec	**$3,710**
75 HP	Standard	2 of CDBR-4045B with 2 of URS000143	M2	119 HP =	159%	9.78 HP =	13%	1035 KJ =	1387 HP-sec	**$2,662**
75 HP	Decel	2 of CDBR-4045B with 2 of URS000141	M2	119 HP =	159%	4.62 HP =	6%	289 KJ =	387 HP-sec	**$2,230**
100 HP	Continuous	2 of CDBR-4220B with 2 of URS000167	M2S3	168 HP =	168%	110 HP =	110%	Cont	inuous	**$15,336**
100 HP	Heavy	2 of CDBR-4220B with 2 of URS000120	M2S2	192 HP =	192%	58.8 HP =	59%	6732 KJ =	9024 HP-sec	**$9,406**
100 HP	Medium	2 of CDBR-4220B with 2 of URS000118	M2S2	192 HP =	192%	30.5 HP =	30%	2144 KJ =	2874 HP-sec	**$7,052**
100 HP	Standard	1 of CDBR-4220B with 1 of URS000119	M1	192 HP =	192%	14.7 HP =	15%	1199 KJ =	1607 HP-sec	**$3,488**
100 HP	Decel	1 of CDBR-4220B with 1 of URS000117	M1	192 HP =	192%	7.61 HP =	8%	466 KJ =	625 HP-sec	**$2,905**

Other Cost Factors

- *Space used for DB Resistors*
  They get ***hot !!***
- *Added heat to air-conditioned space.*

Indirect Costs are
Hard to Quantify,
but very real

The End – Any Questions?

Think Line 'Regen'

It's Green