What is Power Factor?

Power Factor is the ratio of the ***amount of energy used to do real work*** and the ***amount of total energy used to do that work***.

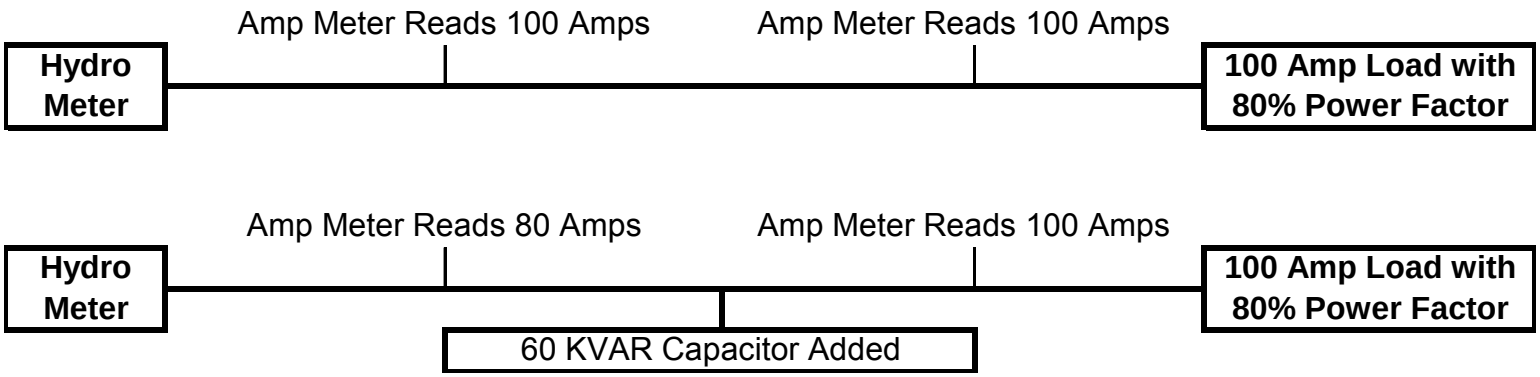
- Related to motors, transformers, DC Drives, lighting ballasts etc.

What is Power Factor Correction?

Power Factor Correction is the application of capacitors to;

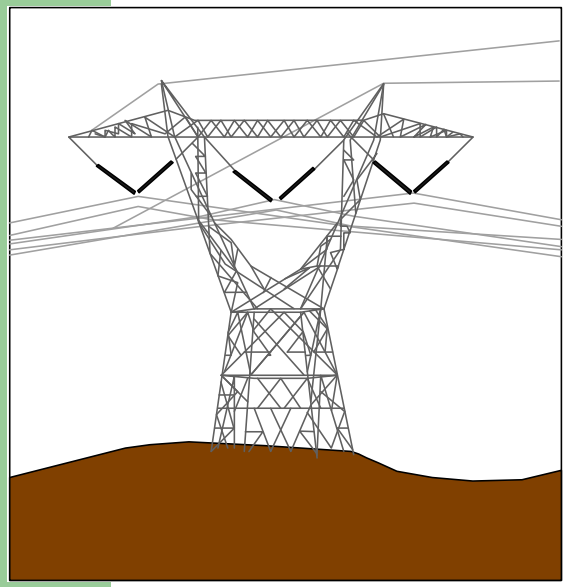
- ***Reduce*** hydro billings
- ***Decrease*** the load on transformers and related equipment
- ***Decreased*** heat losses

Decreased Demand Load



Why is there a Demand Charge anyway?

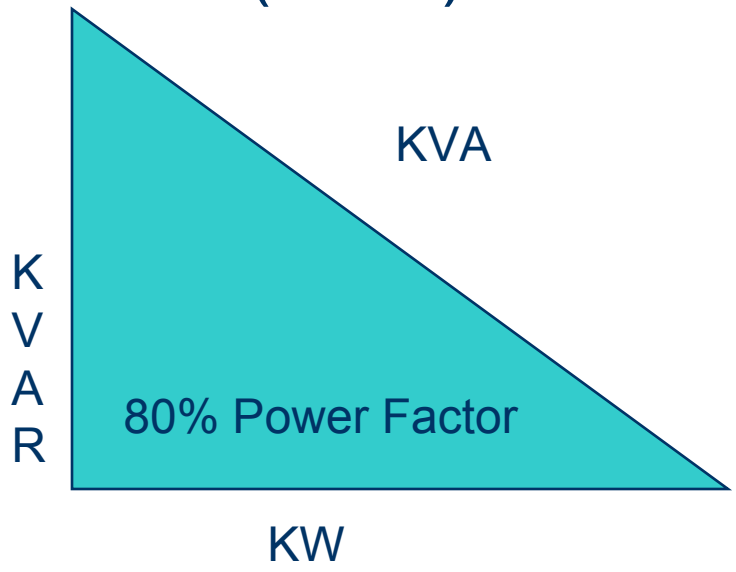
- Why not just pay for the kWh's you use?

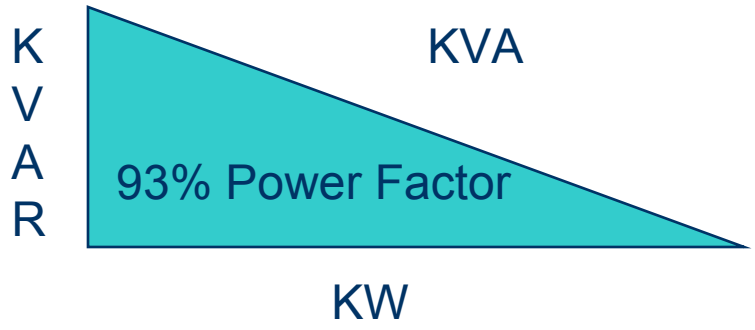


- OPA is committed to produce on demand what ever the consumer requires at any one time
- Generating facilities and carrying facilities must be sized for peak demands

Pythagorean Theorem
KVA = 5 KW = 4 KVAR = 3

- KVA = √(KW^2+KVAR^2)
- 5= √(16+9) +1.5 KVAR 4.3=√(16+2.25)





The Two Parts of a Hydro Bill

- Energy Consumption (Kilowatt hours)
- Demand Kilowatt
  (greater of 100% KW or 90% KVA based on a 15 min or 1 hour sliding window)
- Volts x Amps = VA (volt amps)
- Volts x Amps x PF = W (watts)

A Sample Hydro Bill

CURRENT USAGE INFORMATION

Meter No	Rate Code	# Days	Current Read Date	Current Reading	Previous Read Date	Previous Reading	Multiplier	Metered Usage kWh	Adjustment Factor	Billed Usage kWh	Demand kW
192488	GSDEM	35	28/04/2009	1172	24/03/2009	572	360	216000	1.0360	223776	425

Electricity you used this billing period

Current read 1172 less Previous read 572 equals 600

Electricity you used in kilowatt-hours(600x360x1.0360) 223776

Demand KW is the greater of 100% KW or 90% of KVA

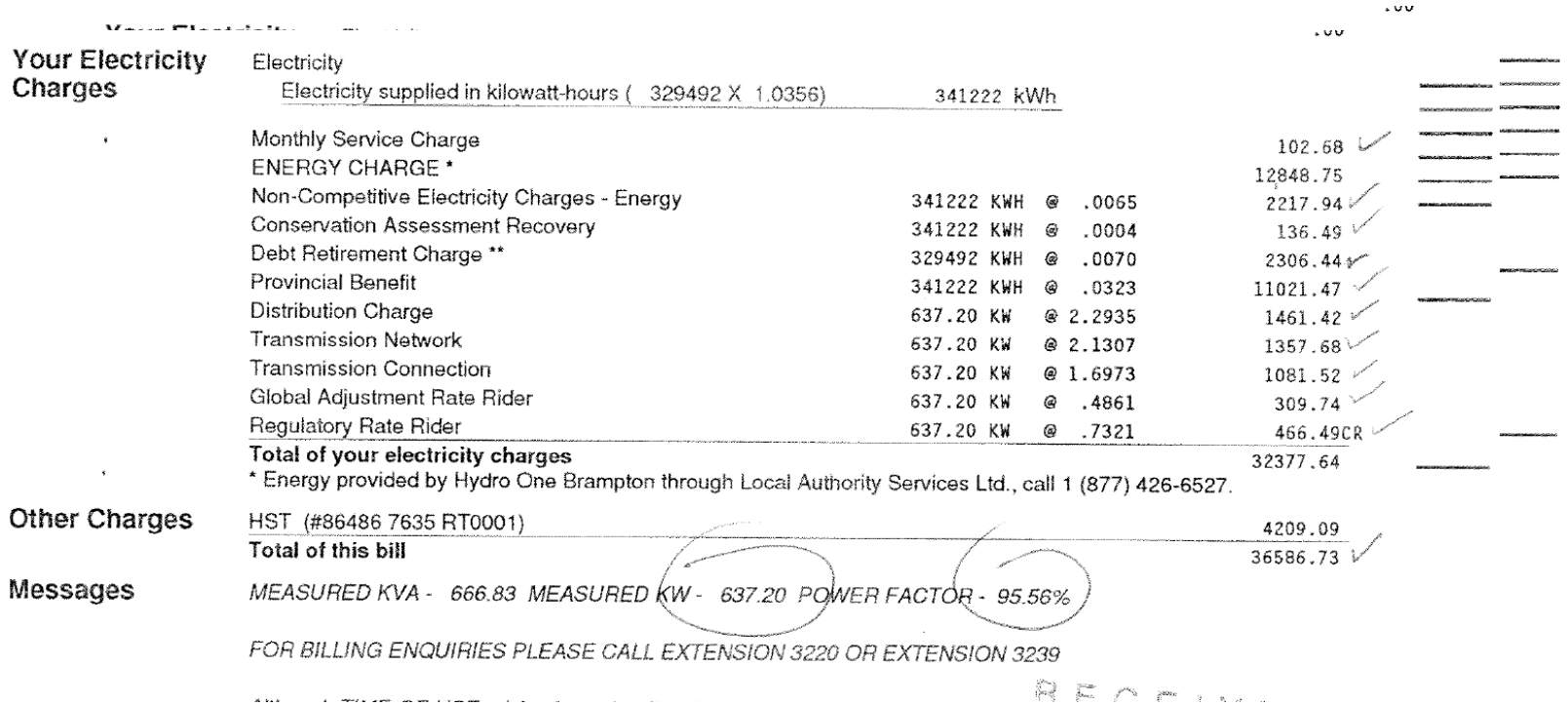
ENERGY MANAGEMENT INFORMATION

BILL MONTH	NO. OF DAYS	ENERGY USED	KWH PER DAY
Apr 09	35	216000	6171
Apr 08	27	116640	4320
Apr 07	29	116640	4022

POWER FACTOR

83.0%

A Sample Hydro Bill



Your Electricity Charges	Electricity		
	Electricity supplied in kilowatt-hours (329492 X 1.0356)	341222 kWh	
	Monthly Service Charge		102.68
	ENERGY CHARGE *		12848.75
	Non-Competitive Electricity Charges - Energy	341222 KWH @ .0065	2217.94
	Conservation Assessment Recovery	341222 KWH @ .0004	136.49
	Debt Retirement Charge **	329492 KWH @ .0070	2306.44
	Provincial Benefit	341222 KWH @ .0323	11021.47
	Distribution Charge	637.20 KW @ 2.2935	1461.42
	Transmission Network	637.20 KW @ 2.1307	1357.68
	Transmission Connection	637.20 KW @ 1.6973	1081.52
	Global Adjustment Rate Rider	637.20 KW @ .4861	309.74
	Regulatory Rate Rider	637.20 KW @ .7321	466.49CR
	Total of your electricity charges		32377.64
	* Energy provided by Hydro One Brampton through Local Authority Services Ltd., call 1 (877) 426-6527.		
Other Charges	HST (#86486 7635 RT0001)		4209.09
	Total of this bill		36586.73
Messages	*MEASURED KVA - 666.83 MEASURED KW - 637.20 POWER FACTOR - 95.56%*		
	FOR BILLING ENQUIRIES PLEASE CALL EXTENSION 3220 OR EXTENSION 3239		

KVA, KW and Power Factor is shown

Typical Billing Table

Year	Month	KVA	KW	Billing Demand .9 of KVA	Actual P.F.	P.F. Penalty	KVAR Req'd
2011	Jan	1241	1084	1117	87.4%	$246	79
2011	Feb	1395	1161	1256	83.2%	$714	212
2010	Mar	1180	1007	1062	85.3%	$417	129
2010	Apr	1156	1003	1040	86.8%	$281	89
2010	May	1528	1321	1375	86.5%	$406	128
2010	Est	1375	1180	1238	85.8%	$433	135
2010	Jul	1430	1223	1287	85.5%	$478	148
2010	Aug	1370	1150	1233	83.9%	$624	188
2010	Sep	1420	1209	1278	85.1%	$523	161
2010	Oct	1373	1145	1235	83.4%	$679	203
2010	Nov	1368	1189	1231	87.0%	$313	99
2010	Dec	1294	1076	1165	83.1%	$666	198
						$5,779	

To Ensure 90 % PF Each Month, use 212 KVAR

Billing Demand with PF Savings

Year	Month	KVA	KW	Billing Demand .9 of KVA	Actual P.F.	P.F. Penalty	KVAR Instl'd
2011	Jan	1181.1	1083.9	1083.9	91.78%	$0	135
2011	Feb	1325.2	1160.7	1192.7	87.59%	$240	135
2010	Mar	1115.6	1006.5	1006.5	90.22%	$0	135
2010	Apr	1095.2	1003.0	1003.0	91.58%	$0	135
2010	May	1464.7	1320.9	1320.9	90.19%	$0	135
2010	Jun	1311.0	1180.0	1180.0	90.01%	$0	135
2010	Jul	1364.6	1222.9	1228.1	89.62%	$39	135
2010	Aug	1301.6	1149.9	1171.5	88.34%	$162	135
2010	Sep	1354.3	1208.7	1218.9	89.24%	$77	135
2010	Oct	1303.0	1144.8	1172.7	87.86%	$209	135
2010	Nov	1306.5	1189.4	1189.4	91.04%	$0	135
2010	Dec	1224.5	1076.1	1102.1	87.88%	$195	135
						$922	

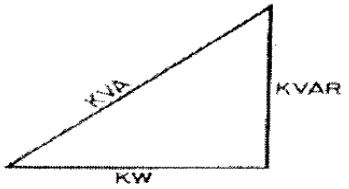
Avg PF
89.61%

135 KVAR WOULD HAVE REDUCED ANNUAL PENALTIES TO

THEREFORE SAVING $4,857

I (squared) R Losses (Uncorrected)

THIS VECTOR REPRESENTS THE INDUCTIVE LOADING ON A 5 H.P. MOTOR.



KVA = 5.27 KVA = TOTAL POWER
KVAR = 3.73 KVAR = REACTIVE POWER
KW = 3.73 KW = REAL POWER

POWER FACTOR = .70

TOTAL CURRENT = 21.95 AMPS
WORKING CURRENT = 15.54 AMPS
REACTIVE CURRENT = 15.54 AMPS

THE CONDUCTORS SUPPLYING THIS MOTOR MUST BE ACCORDING TO N.E.C. TABLE #310-16 #10 COPPER OR LARGER. THE RESISTANCE IS 1.06 OHMS PER 1000'. THIS MOTOR IS 250' FROM THE ELECTRICAL PANEL AND IN A 1Ø CIRCUIT WILL HAVE A TOTAL OF .25 OHMS RESISTANCE.

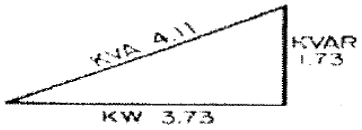
POWER REQUIRED:
WORK 3.730 KW
I^2R LINE LOSS .120 KW
TOTAL 3.850 KW

3.1% in losses

=$4 per month

I (squared) R Losses (Corrected)

CORRECTING THIS CIRCUIT WITH A 2KVAR CAPACITOR:



KW = 3.73
KVAR = 1.73
KVA = 4.11

TOTAL CURRENT = 17.13
WORKING CURRENT = 15.54
REACTIVE CURRENT = 7.21

POWER FACTOR = .91

TOTAL POWER:

WORK 3.730 KW
I^2R LINE LOSS .073 KW
TOTAL 3.803 KW

THE SAVING FROM I^2R MAY BE BEST UNDERSTOOD IF WE USE A NEW FORMULA.

$(X^2-Y^2)R$

X = AMPS IN CIRCUIT BEFORE CORRECTION

Y = AMPS IN CIRCUIT AFTER CORRECTION

R = RESISTANCE IN OHMS

TOTAL POWER BEFORE = 3.850 KW
TOTAL POWER AFTER = 3.803 KW
.047 KW

OR 47 WATTS OF SAVINGS PER HOUR OF USE.

1.2% Recovered Losses on 12% reduction in current

$1.60 monthly savings

Savings Calculations (KVA Hours)

Phase to Ground Voltage - 289 Voltage: 485 Circuit Master(CM) Used: CM303

Before Installation:

Amperes: Leg 1 - 260 Leg 2 - 280 Leg 3 - 260 Total 800 AVG: 266.67 KVAR: 53.57 PF: 0.88

After Installation:

Amperes: Leg 1 - 210 Leg 2 - 240 Leg 3 - 220 Total: 670 AVG: 223.33 KVAR: 10 PF:: 0.99

Amp % Savings 16.25 KVAR % Savings 81.33 PF % Improvement 11.111

Hours/Day: 24 Day/Year: 312 Cost of 3964.80 Billing Rate(kwh): 0.11

Return on Investment

WATTS = VOLTAGE x AMPS x SQ. ROOT OF 3 PHASE / 1000 = KILOWATTS
Annual Cost of Operation = KW x BILLING RATE x HRS/DAY x DAYS/YEAR

Before Installation:

Annual Cost: 485 x 266.7 x 1.732 = 224033.33 / 1000 = 224.03 x .11 x 24 x 300 = **$177434.39**

After Installation:

Annual Cost: 485 x 223.3 x 1.732 = 187576.46 / 1000 = 187.57 x ..11 x 24 x 300 = **$ 148560.55**

SAVINGS $177,434.39 MINUS $148,560.55 EQUALS $28,873.84

ROI / Months 1.65

Savings Calculations (Fantasy KW)

- Corrected Formula

Before Installation

Annual Cost: 485 x 266.7 x 1.732 = 224033.33 /1 000 = 224.03 (x .88 = 197) x .11 x 24 x 300 = $156,139.94

After Installation

Annual Cost: 485 x 223.3 x 1.732 = 187576.46 /1 000 = 187.57 (x .99 = 185.7) x .11 x 24 x 300 = $147,074.40

SAVINGS $156,139.94 MINUS $147,074.40 EQUALS $9,065.54

- Results Using KVAR and Using Power Factor

	KVA	KVAR	KW	PF
Before	224.03	53.57	217.53	97.1%
After	187.57	10	187.30	99.9%
KVAR Added		**44**		

	KVA	KVAR	KW	PF
Before	224.03	106.41	197.15	88.0%
After	187.57	26.46	185.69	99.0%
KVAR Added		**80**		

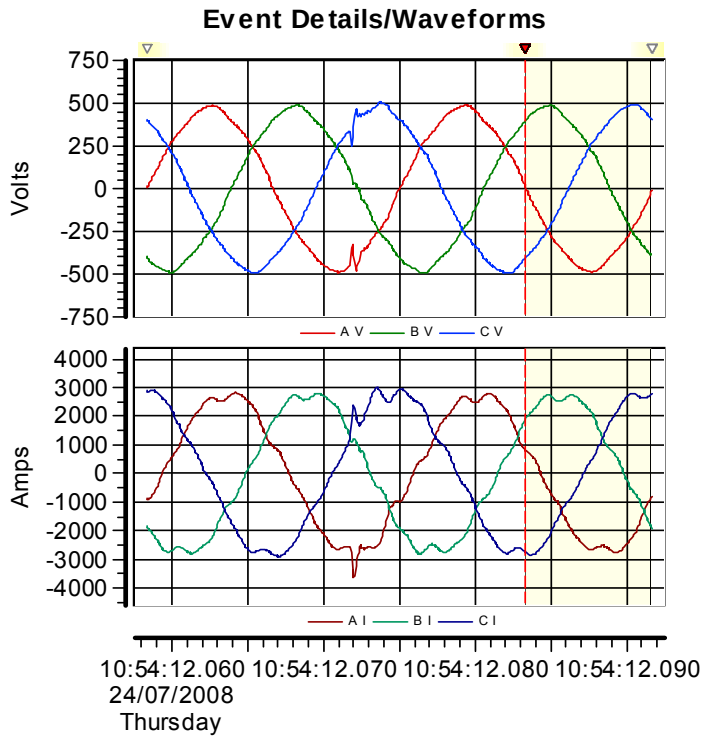
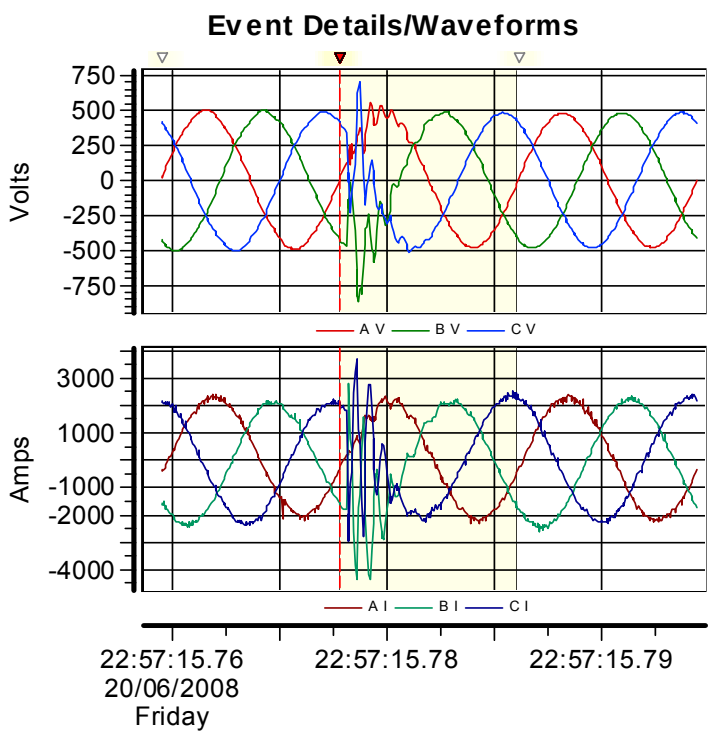
Kilowatt Recovery / 100 KVAR Installed

- 500 KVA Demand - 400 KW Demand – 50 KVA Reduction
- At 80% PF, about 10% KVA reduction possible to 90% PF
- Consider 10% KW loss recovery on the reduction (1% overall)
- 100 kVAr distributed throughout plant 4 KW/Hr
- Plant operates 5 days x 16 hr's = 336 hr/month
- Kilowatt reduction per month = 1,344 KW/hr's
- Monthly Billing Demand recovery @ $7 = $350
- Monthly Kilowatt hour recovery @ 10 cents KW/hr = $134
- Installed Cost 100 kVAr Fixed at Main = $6,000
- Annual recovery (no KW losses) $350 x 12 = $4,200
- Installed Cost 13 x 7.5 KVAr on 25 HP Motors = $6,500
- Annual recovery (with KW losses) ($350+$134) x 12 = $5,800
- Can you see a 1.6%, 1,344 KW/hr reduction on 83,294 KW/hr's. Most PF manufacturers use .5% to 1.5%

Types of Conventional Capacitors

- Base capacitance (fixed) 10% to 15% kVAr to Transformer KVA size
- Greater than 10% to 15%, use automatically switched
- Switched banks
  Central Automatic
  Load side of contactor ALS
  Separate contactor for LV start

Conventional Capacitors and Harmonics

Hydro One Capacitor switching Transient with capacitors OFF	Hydro One Capacitor switching Transient with capacitors ON
	

Event #31 at 24/07/2008 10:54:12.083
CVPeakHigh To Normal
Threshold crossed 500.0

Event #1050 at 20/06/2008 22:57:15.775
BVTrans Rel. trans. Normal To High
Threshold crossed 300.0 V
Magnitude 380.5 V
Phase 15.0 Deg

Harmonic Filtered Capacitors

- Fixed harmonic filters 2 ½ times cost of conventional
- Automatic harmonic filters 50% higher than conventional
- Consider use of high harmonic capacitor cells that can be upgraded to a filtered back if future conditions require

Capacitors and Nominal Voltage

- *The amount of kVAr is based on a nominal voltage of 600 volts. As the voltage increases above nominal, the amount of useable kVAr increases and as the voltage decreases below nominal, the amount of useable kVAr decreases. For example, 130 kVAr rated at 600 volts will only deliver 119.4 kVAr at 575 volts. Conversely, it would deliver 136.6 kVAr at 615 volts.*

Maximum Fixed Capacitor Sizes for Disconnects/Breakers 150% not 135%

Disconnect Size	208 Volts	480 Volts	600 volts
30 amps	7.5	15	20
60 Amps	15	30	40
100 Amps	22.5	55	65
200 Amps	45.1	110	135
400 Amps	90.1	220	280

PF Correction Multipliers

ACTUAL POWER FACTOR	TARGET POWER FACTOR									
	0.70	0.75	0.80	0.85	0.90	0.92	0.94	0.96	0.98	1.00
0.40	1.27	1.41	1.54	1.67	1.81	1.87	1.93	2.00	2.09	2.29
0.45	0.96	1.10	1.23	1.36	1.50	1.56	1.62	1.69	1.78	1.98
0.50	0.71	0.85	0.98	1.11	1.25	1.31	1.37	1.44	1.53	1.73
0.55	0.50	0.64	0.77	0.90	1.03	1.09	1.16	1.23	1.32	1.52
0.60	0.31	0.45	0.58	0.71	0.85	0.91	0.97	1.04	1.13	1.33
0.65	0.15	0.29	0.42	0.55	0.68	0.74	0.81	0.88	0.97	1.17
0.70	0.00	0.14	0.27	0.40	0.54	0.59	0.66	**0.73**	0.82	1.02
0.75		0.00	0.13	0.26	0.40	0.46	0.52	0.59	0.68	0.88
0.80			0.00	0.13	0.27	0.32	0.39	0.46	0.55	0.75
0.85				0.00	0.14	0.19	0.26	0.33	0.42	0.62
0.90					0.00	0.06	0.12	0.19	0.28	0.48

KVAR for Motors for 95% PF

T-Frame NEMA Class B Motors

NEMA Class B T-Frame Motors
Normal Starting Torque — Normal Running Current

HP Rating	3600 RPM kVAR	%R	1800 RPM kVAR	%R	1200 RPM kVAR	%R	900 RPM kVAR	%R	720 RPM kVAR	%R	600 RPM kVAR	%R
3	1.5	14	1.5	23	2.5	28	3	38	3	40	4	40
5	2	14	2.5	22	3	26	4	31	4	40	5	40
7.5	2.5	14	3	20	4	21	5	28	5	38	6	45
10	4	14	4	18	5	21	6	27	7.5	36	8	38
15	5	12	5	18	6	20	7.5	24	8	32	10	34
20	6	12	6	17	7.5	19	9	23	10	29	12	30
25	7.5	12	7.5	17	8	19	10	23	12	25	18	30
30	8	11	8	16	10	19	14	22	15	24	22.5	30
40	12	12	13	15	16	19	18	21	22.5	24	25	30
50	15	12	18	15	20	19	22.5	21	24	24	30	30
60	18	12	21	14	22.5	17	26	20	30	22	35	28
75	20	12	23	14	25	15	28	17	33	14	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	36	12	35	12	42	14	45	15	50	17
150	30	10	42	12	40	12	52.5	14	52.5	14	60	17
200	35	10	50	11	50	10	65	13	68	13	90	17
250	40	11	60	10	62.5	10	82	13	87.5	13	100	17
300	45	11	68	10	75	12	100	14	100	13	120	17
350	50	12	75	8	90	12	120	13	120	13	135	15
400	75	10	80	8	100	12	130	13	140	13	150	15
450	80	8	90	8	120	10	140	12	160	14	160	15
500	100	8	120	9	150	12	160	12	180	13	180	15