POWER FACTOR IMPROVEMENT CONCEPT
FOR CEMENT PLANTS

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POWER FACTOR REQUIREMENTS FOR A MODERN CEMENT PLANT

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Power factor correction
WHAT IS POWER FACTOR?
1. THE UTILITY IS REQUIRED TO SUPPLY POWER (kVA) THAT INCLUDES A COMPONENT OF REACTIVE POWER (kVAr) AND A COMPONENT OF REAL POWER (kW)

2. THE REAL POWER (kW) IS WHAT IS ABSORBED BY THE LOAD AND DISSIPATED AS ELECTRICAL HEAT LOSES.

3. THE REACTIVE POWER (kVAr) IS REQUIRED BY THE MAGNETIC CIRCUIT TO PRODUCE TORQUE (MOTOR) OR INDUCE VOLTAGE (TRANSFORMER)
POWER FACTOR CONCEPT

THE APPARENT POWER \((\text{kVA})\) SUPPLIED BY THE UTILITY IS THE RESULT OF THE QUADRATIC SUM GIVEN BY THE FOLLOWING EQUATION

\[
\text{kVA} = \left[\text{kW}^2 + \text{kVAr}^2\right]^{1/2}
\]

THE POWER FACTOR \((\text{PF})\) IS THE VALUE OF THE COSINE OF THE ANGLE \(\Phi\) RESTING BETWEEN THE VECTORS DEFINING THE ACTIVE POWER AND THE APPARENT POWER

\[
\text{PF} = \cos \Phi = \frac{\text{kW}}{\text{kVA}}
\]
POWER FACTOR IMPROVEMENT CONCEPT

UNCOMPENSATED MOTOR CIRCUIT

Typical Power Flow in Motor Circuit

- **S**: Apparent power kVA
- **Q**: Reactive kVar
- **W**: Active power kW
- **P**: Mechanical power kW

Vector Diagram

- **OA**: Active power W (kW)
- **OB**: Inductive reactive power Q (kVar)
- **OC**: Apparent power s (kVA)
- **CD**: Leading reactive power compensation Q’ (kVar)
- **Φ**: Phase angle uncompensated
- **Φ’**: Phase angle compensated
METHODS FOR IMPROVING POWER FACTOR

CAPACITOR BANKS

SYNCHRONOUS MOTORS
POWER FACTOR IMPROVEMENT USING CAPACITORS

FEATURES

- BUILDING BLOCKS OF STANDARD kVAR units to desired capacity
- COULD BE SWITCHED IN BANKS AT MCC WITH POWER FACTOR CONTROLLER OR WITH THE INDIVIDUAL INDUCTION MOTOR
- TYPICALLY APPLIED IN LOW VOLTAGE CIRCUITS (380 –690V)
- MORE EXPENSIVE FOR MEDIUM VOLTAGE (3.8kV – 6.9kV)
- DEPENDING ON THE SIZE OIL CONTAINMENT IS REQUIRED & ENCLOSURES
- FLAMMABLE DIELECTRIC
- REQUIRE FILTER REACTORS TO DE-TUNE HARMONIC FREQUENCIES
- VULNERABLE TO SWITCHING SURGES
- COMPENSATION LIMITED TO 0.95 LAGGING POWER FACTOR DUE TO OVEREXCITATION AND SWITCHING RESONANCE.
- kVAR OUTPUT ~ (TERMINAL VOLTAGE)^{-1/2}
POWER FACTOR CORRECTION USING CAPACITORS

Typical Power Flow in Motor Circuit

- **S**: Apparent power kVA
- **Q**: Reactive kVar
- **W**: Active power kW
- **P**: Mechanical power kW

Vector Diagram

- **OA**: Active power W (kW)
- **OB**: Inductive reactive power Q (kVar)
- **OC**: Apparent power S (kVA)
- **CD**: Capacitor reactive power Q’ (kVar)
- **Φ**: Phase angle uncompensated
- **Φ’**: Phase angle compensated
- **OD**: New apparent power from utility S’
OPEN CAPACITOR BANK INSTALLATION
POWER FACTOR IMPROVEMENT USING SYNCHRONOUS MOTORS

- SYNCHRONOUS MOTORS WITH UNITY POWER FACTOR (PF=1.0)
- SYNCHRONOUS MOTORS WITH LEADING POWER FACTOR –OVEREXCITED (PF= 0.9 –0.8 LEADING)
IMPROVING POWER FACTOR USING SYNCHRONOUS MOTORS

FEATURES

- Dynamically compensates and improves power factor and voltage levels as dictated by the plant load
- Reactive compensation proportional with DC excitation level
- Unity or leading power factor capabilities which could be used to compensate the entire plant power system
- Can run decoupled as a synchronous condenser (Requires a Fluid Coupling or an Air Clutch to De-Clutch from the Driven Machine)
- Requires little maintenance - Brushless Exciters
- Most economical for plant installations requiring significant PF compensation
- Most economical for 2000 kW and larger loads
- Output proportional with terminal voltage
- Low starting current inrush and low torque requirements when coupled with controlled filled fluid couplings or Air Clutch
SYNCHRONOUS MOTOR APPLICATION

1. BALL MILLS – WITH CONTROLLED FILL FLUID COUPLING or Air clutch

2. INDUCED DRAFT FANS WITH OR WITHOUT SPEED CONTROL – WITH CONTROLLED FILL FLUID COUPLING

3. VERTICAL MILLS WITH HYDRAULIC LIFTERS (LOESCHE, FLS, KHD, ETC) – DIRECT COUPLED

4. VERTICAL MILLS WITHOUT HYDRAULIC LIFTERS – WITH CONTROLLED FILL FLUID COUPLING or cycloconverter (POLYSIUS, PFEIFFER, Etc, High starting and breakdown torques)
POWER FACTOR CORRECTION USING SYNCHRONOUS MOTORS

Typical Power Flow in Motor Circuit

- **S**: Apparent power kVA
- **Q**: Reactive kVar
- **W**: Active power kW
- **P**: Mechanical power kW

UTILITY Generator

SYNCHRONOUS Motor
POWER FACTOR IMPROVEMENT USING SYNCHRONOUS MOTOR WITH
UNITY AND LEADING POWER FACTOR

Vector Diagram

OA: Active power W (kW)
OB: Inductive reactive power Q (kVar)
OC: Apparent power S (kVA)
CD: Reactive power compensation Q': (kVar) for unity PF
Φ': Phase angle compensated
OD: New apparent power from utility S' at unity PF
AE: Equivalent leading PF capacitor bank replaced = 25% of
nameplate kVA of motor to compensate the balance of
plant. Machine kVA S' = S.

S' = W, Φ = 0°,
COS’ Φ = 1

S' = S, Φ = -30°,
COS Φ = .8
SYNCHRONOUS MOTOR WITH VARIABLE SPEED FLUID COUPLING
SYNCHRONOUS MOTOR WITH CONTROLLED FILL FLUID COUPLING 8200 HP RAW MILL ID FAN
5400 kW BALL MILL DRIVE WITH SYNCHRONOUS MOTOR and CONTROLLED FILLED FLUID COUPLING
APPLICATION EXAMPLE -A

Option 1
PREHEATER ID fan with VFD + Induction Motor

Option 2
PREHEATER ID fan with Synchronous motor with controlled fill variable speed fluid coupling
## INVESTMENT COST ANALYSIS - EXAMPLE A - 5000HP, 890 RPM PREHEATER ID FAN DRIVE

<table>
<thead>
<tr>
<th>OPTION 1</th>
<th>OPTION 2</th>
<th>Speed control range -15%, max -34%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOTOR</td>
<td>Synch Motor 0.8 lead PF</td>
<td>$685,000</td>
</tr>
<tr>
<td>$447,000</td>
<td>$190,000</td>
<td>Fluid Coupling</td>
</tr>
<tr>
<td>Transformer</td>
<td>$640,000</td>
<td>Water Cooling</td>
</tr>
<tr>
<td>$165,000</td>
<td>Switchgear</td>
<td>$80,000</td>
</tr>
<tr>
<td>VFD</td>
<td>$275,000</td>
<td>Elec room</td>
</tr>
<tr>
<td>$167,000</td>
<td>Not required</td>
<td>Nil</td>
</tr>
<tr>
<td>Capacitor bank</td>
<td>Total Cost</td>
<td>$1,230,000</td>
</tr>
<tr>
<td>$1,884,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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# DRIVE TRAIN EFFICIENCY ANALYSIS - EXAMPLE A

## 5000 HP, 890 RPM, PREHEATER ID FAN DRIVE TRAIN

<table>
<thead>
<tr>
<th>OPTION 1</th>
<th>Efficiency %</th>
<th>OPTION 2</th>
<th>Efficiency %</th>
<th>15% speed change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction Motor</td>
<td>95.6 @ 60Hz - 51Hz</td>
<td>Synchronous Motor (actual 98.1%)</td>
<td>97.4@60Hz min guaranteed</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>99.1@60 Hz</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>VFD Electronics</td>
<td>98</td>
<td>Fluid coupling slip 2.5% @100% 1.3% @85%</td>
<td>97.5 @100 speed 98.7@85%speed</td>
<td></td>
</tr>
<tr>
<td>Filter loss 1500kVAR -1%</td>
<td>99.6</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Drive train Efficiency</td>
<td>92.47 @ 60Hz-51Hz</td>
<td>Drive train efficiency</td>
<td>94.9@100% 96.13@85% speed</td>
<td></td>
</tr>
<tr>
<td>AVG 87.22kW, 8250hrs/year/$0.055/kwhr</td>
<td>$39,576 annual savings</td>
<td>Efficiency gain 2.43%, 3.66% @85%</td>
<td>90.6kW@100% 83.84kW@85% 87.22kw average</td>
<td></td>
</tr>
</tbody>
</table>
APPLICATION EXAMPLE A - 5000HP PREHEATER ID FAN DRIVE SYSTEM

OPTION 2 ADVANTAGES

1. Lower initial capital cost by $654,000
3. Lower maintenance and fewer components
4. Higher reliability resulting in higher OEE particularly of PREHEATER application
5. Lower clinker cost factor in this application
6. Dynamic power factor compensation and voltage stability to the rest of the plant by virtue of the leading power factor.
APPLICATION EXAMPLE - B

- Cement plant with 40 MVA demand 0.85 pf, equivalent 34 MW POWER DEMAND. NEED TO BE CORRECTED TO 0.95 PF LAG.

- MAIN EQUIPMENT; 6200HP, 900 RPM RAW MILL, 5000HP, 900 RPM ID FAN, 2X5400HP 1200RPM BALL MILS

- OPTION 1- USE SLIP RING MOTORS WITH POWER FACTOR CORRECTION CAPACITORS

- OPTION 2- USE SYNCHRONOUS MOTORS WITH FLUID COUPLING, UNITY POWER FACTOR MOTORS
### APPLICATION EXAMPLE B - 40MVA, 0.85 lag PF PLANT DEMAND, 2X5400HP, 1200 rpm BALL MILL DRIVES, compensate to 0.95 lag

<table>
<thead>
<tr>
<th>OPTION1</th>
<th>SLIP RING MOTORS RHEOSTAT: 6200hp raw mill, 5000hp RM fan 2x5400hp ball mills</th>
<th>OPTION2</th>
<th>SYNCHRONOUS MOTOR, 1.0 PF 6200hp raw mill, 5000hp RM fan, 2x5400hp ball mills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball mill motors</td>
<td>2x$397,000=$794,000</td>
<td>Ball mill motors</td>
<td>2x$360,000=$720,000</td>
</tr>
<tr>
<td>Raw mill motor</td>
<td>1x$415,000=$415,000</td>
<td>Raw mill motors</td>
<td>1x$390,000=$390,000</td>
</tr>
<tr>
<td>Raw Mill ID fan</td>
<td>1x$420,000=$420,000</td>
<td>Raw Mill ID fan</td>
<td>1x$375,000=$375,000</td>
</tr>
<tr>
<td>Capacitor filter bank and switchgear to 0.95 PF 3x1500kVar, 1x2000kVar</td>
<td>3x$28,000=$84,000 1x$31,000=$31,000</td>
<td>Fluid coupling 1.8% slip</td>
<td>4x$180,000=$720,000</td>
</tr>
<tr>
<td>Capacitor bank for the remainder of the plant 10000kVar -6,500kVar=3,500kVar</td>
<td>1x$45,000=$45,000</td>
<td>With unity power factor synch motors the plant operates at 95.2PF.</td>
<td>Leading PF SYN motors not needed.</td>
</tr>
<tr>
<td>Total Equipment cost</td>
<td>$1,789,000</td>
<td></td>
<td>$2,205,000</td>
</tr>
</tbody>
</table>

Difference in initial investment cost $416,000
APPLICATION B – 40MVA PLANT CORRECTED TO 0.95 PF= 35.78MVA DEMAND FROM UTILITY

<table>
<thead>
<tr>
<th>OPTION 1</th>
<th>EFFICIENCY</th>
<th>OPTION 2</th>
<th>EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>BALL MILL MOTORS</td>
<td>0.945</td>
<td>SYNCH MOTORS</td>
<td>0.981 x.982= 0.9633</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BALL MILL</td>
<td></td>
</tr>
<tr>
<td>RAW MILL MOTOR</td>
<td>0.945</td>
<td>RAW MILL MOTOR</td>
<td>0.978x0.982=0.960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RAW MILL MOTOR</td>
<td></td>
</tr>
<tr>
<td>RAW MILL ID FAN</td>
<td>0.945</td>
<td>RAW MILL ID FAN</td>
<td>0.978x0.982=0.960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RAW MILL ID FAN</td>
<td></td>
</tr>
<tr>
<td>CAPACITORS 10,000 MVAR@99%EFF</td>
<td>0.9972</td>
<td>FLUID COUPLING</td>
<td>0.982</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLUID COUPLING</td>
<td></td>
</tr>
<tr>
<td>OVERALL MAIN DRIVES ELECTRICAL EFFICIENCY</td>
<td>0.942</td>
<td>OVERALL EFFICIENCY</td>
<td>0.9611</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OVERALL EFFICIENCY</td>
<td></td>
</tr>
<tr>
<td>AVG operating 8250hrs per year –cost of electricity $0.055/kwh</td>
<td>$142,232 electrical energy savings per year using synchronous motors.</td>
<td>Payback in 2.9 years</td>
<td>DIFFERENCE IS 1.91% OR 313.46kW per hour in favor of synch motors</td>
</tr>
</tbody>
</table>
APPLICATION B – 40MVA PLANT

OPTION 2 - ADVANTAGE

• 1.91% higher operating efficiency – savings in electrical energy of $142,200 per year.
• Lower maintenance and fewer components, no brushes to replace.
• Higher reliability resulting in higher OEE particularly nor brush and collector issues.
• Lower clinker cost factor in this application.
• Dynamic power factor compensation and voltage stability to the rest of the plant by virtue of the leading power factor.
• Lower real estate required than for slip ring motor
• Payback in 2.9 years at current energy rates. Demand $ not included

Disadvantage
• Higher initial operating cost by $416,000
END