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FOREWORD

THE THIRTY-FORTH IEEE CEMENT INDUSTRY TECHNICAL CONFERENCE

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The Industry Applications Society's
Cement Industry Committee
of the
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The 1992 IEEE Cement Industry Technical Conference completes 34 years of this activity. Only the dedication and perseverance of Cement Industry Committee Members and of the Annual Program Committee Members enable us to continue to present these annual affairs with the professionalism that exists. To those people who participated in these various activities, we give our thanks and gratitude.

The Technical Papers contained in this Conference Record have been prepared using guidelines from the "*Authors Guide*" of the Industry Applications Society (IAS) modified by the Cement Industry Committee. We feel confident that these papers will add to your knowledge concerning the various subject matters and, in turn, this knowledge will enable you to discharge the job responsibilities assigned to you with increased efficiency and confidence.

Thanks to all of you for attending our conference. We hope that the papers and activities will enhance your knowledge while entertaining you in our lovely Dallas, Texas.

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SYNCHRONOUS MOTOR FIELD CONTROLLERS AND THEIR APPLICATION

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ABSTRACT:

In the past several years Solid State Technology has made Motor Field Regulation Te niques cost effective.

The effects of Field Voltage, Field Current, Power Factor, and, VAR controllers on the mill power system will be discussed.

IF BUS VOLTAGE STABILITY IS A PRIORITY THEN THE VAR CONTROLLED MOTOR FIELD WILL BE THE CONTROLLER OF CHOICE.

INTRODUCTION:

The ability to control the synchronous motor field and hence the mill power systems vars and voltage has always been attractive. Because of the cost and complexity of synchronous motor field regulators only a limited number of PF, Var or Field Current controlled systems were installed.

However; in the past several years technology has reduced the cost. Simpler field regulators have been developed and hence a demand has risen for this type of control.

This paper is written to aid in the selection of the best field regulator for the application.

In applying a field controller the engineer not only has to be aware of how the motor will react to the field controller but how the power system well react to Voltage Dips and Load Swings.

This paper will first review synchronous motors response to load and field current changes with respect to power factor and var flow. Then it will review what happens to the power system during load swings with various field controllers applied.

It will be shown that a VAR controller will be the controller of choice for constantly changing loads.

A method will be advanced to help control the total mill VAR flow of utilizing VAR controllers and communications equipment currently available.

THE SYNCHRONOUS MOTOR:

To understand what happens to a power system lets first review what happens within the Synchronous Motor. Figure 1 shows the vectors at various impedance components and resultant voltages as the load (output torque) and terminal voltage is held constant.

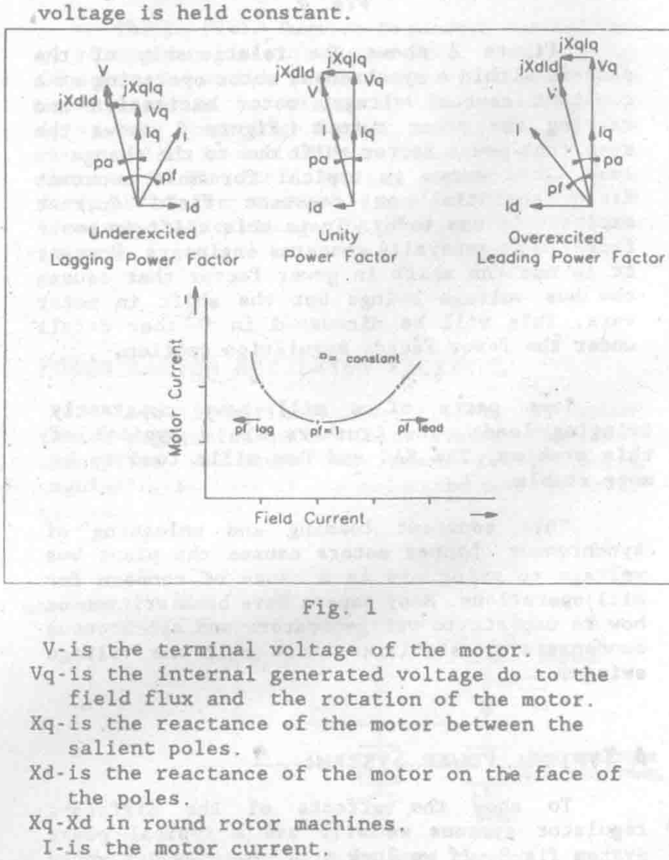

Fig. 1

V-is the terminal voltage of the motor.
Vq-is the internal generated voltage do to the field flux and the rotation of the motor.
Xq-is the reactance of the motor between the salient poles.
Xd-is the reactance of the motor on the face of the poles.
Xq-Xd in round rotor machines.
I-is the motor current.
Iq-is the real current in-phase with the internal generated voltage.
Id-is the reactive current flow.

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Figure 1 shows the relationship of the phasers within a synchronous motor operating at a constant terminal voltage, power output and varying the motor excitation (field current). The resultant "V" curve is shown. A detailed discussion of these vectors is beyond the scope of this paper but see Charles Concordia's and Semual Seely's excellent books on this subject.

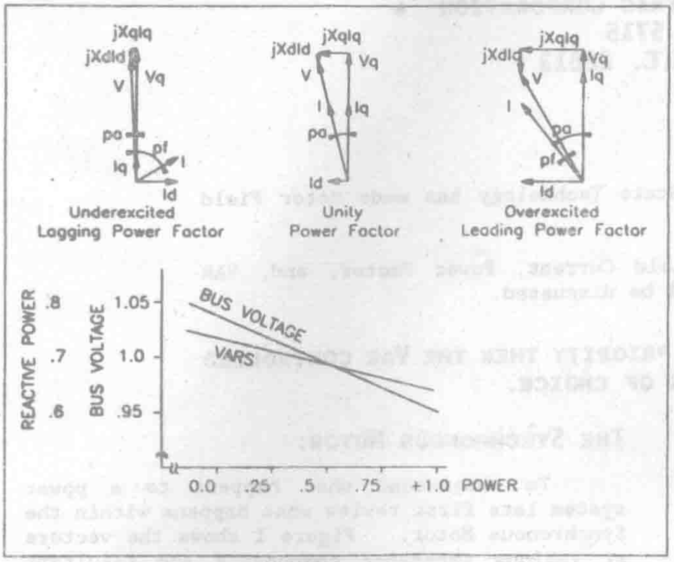

Fig. 2

Figure 2 shows the relationship of the phasers within a synchronous motor operating at a constant source voltage, motor excitation and varying the power output. Figure 2 shows the resultant power factor shift due to the change in load. This curve is typical for most constant field potential or constant field current exciters in use today. It is this shift in power factor that generally concerns engineers. However it is not the shift in power factor that causes the bus voltage swings but the shift in motor vars. This will be discussed in further detail under the Power Factor Regulation section.

Some parts of a mill have constantly swinging loads. The crushers are a typical of this problem. The SAG and Raw mills tend to be more stable.

This constant loading and unloading of synchronous chipper motors causes the plant bus voltage to swing and is a cause of concern for mill operations. Many papers have been written on how to use static var generators and synchronous condensers to stabilize these mill bus voltage swings.

A Typical Power System:

To show the effects of the different regulator systems we will use a typical power system fig 3. If we look at a power system whose total connected load of synchronous motors is 80% of it's incoming transformation and the power system impedance is 10 % of the transformation. Such a typical system could be a refiner or grinder department.

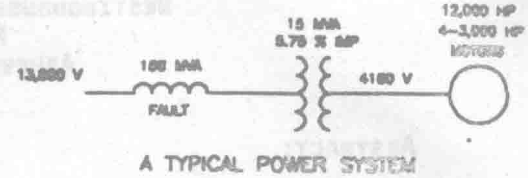

Fig. 3

This typical SAG/Raw mill area consists of 4-4,000 hp 80% leading synchronous motors. The normal load is 6 mills operating at any one time. Being a well designed area it is feed from two different feeders. The following values are chosen to be a soft but workable system. If we used a rock solid system the type field control would be of little interest. The area is fed by 2-15 MVA 13,800 volt primary and 4160 volt secondary 5.75 % impedance transformers. The feeder impedance has a 150 mva fault capability.

Constant Potential Exciters: (Unregulated):

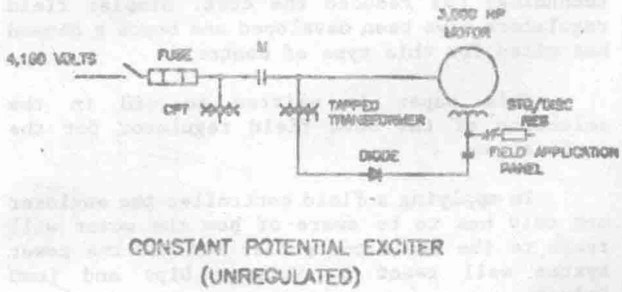

Fig. 4

Figure 4 shows the typical single line for a constant potential exciter in a E2 motor starter.

Constant Potential Exciters are tapped transformers and diode bridges. The output voltage follows the line voltage. Fig 5 contrasts the motor terminal voltage regulation as the motor load swings from 0% to 200 % output power. For this discussion 1 PU voltage is set up as the no motors running condition. The motors are operating at 80% leading power factor at 100% load. At 100% load this leads to a 7% increase in motor terminal voltage and a 5% increase in the bus voltage. However as the motors unload the kw drops, the leading vars increases between 20 to 30% and the power factor drops to 0% leading.

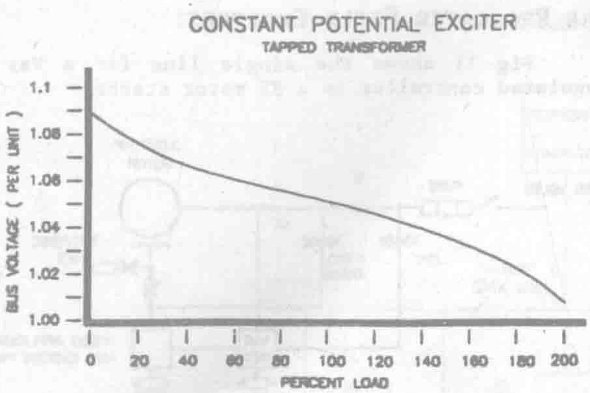

Fig. 5

Where as there is a voltage rise after the motor is started the var flow is reasonably stable once the unit is on line.

Setting the warm full load field current is a somewhat difficult process of reconnecting taps and running the motor again. When the motor is first started up the cold field resistance is low and the field current is about 15 to 30% above normal. It takes about two hours for the field to warm up and the field current to stabilize at its final value.

There are some stability questions: as the motor load decreases the var flow increases, thus increasing the motor terminal voltage which in turn increases the field current which in turn increases the var flow. Like wise as the motors take on load the var flow is decreased dropping the terminal voltage and decreasing the excitation.

If the motor goes into overload and the voltage drops too low and the available pull out torque will decrease perhaps to a dangerous level. The system gain is low in a brushed synchronous motor but can be troublesome in a brushless machine on a soft power system. In the past several installations have experienced this voltage and mechanical oscillation/instability. As a result most constant potential brushless field controllers have a voltage stabilizer (SOLA transformers) installed to limit this effect.

CONSTANT POTENTIAL EXCITER: (REGULATED):

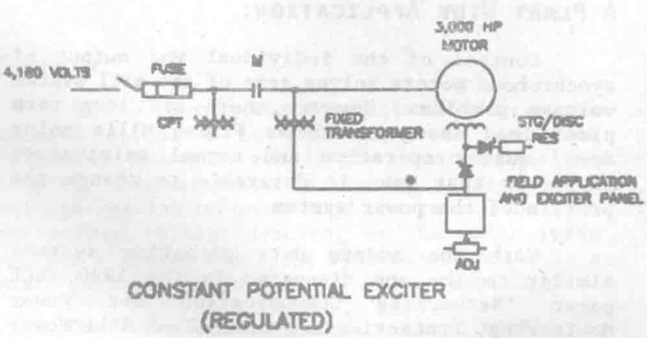

Fig. 6

Figure 6 is the single line for a Constant Potential Exciter (regulated) in a E2 motor starter.

The Field Voltage Regulated Exciter often called the variable voltage exciter consists of a semi-converter (SCR's and Diodes) or full converter (all SCR's) single or three phase. The unit addresses two deficiencies of the Constant Potential Exciters; they are easy to adjust and the stability question is eliminated.

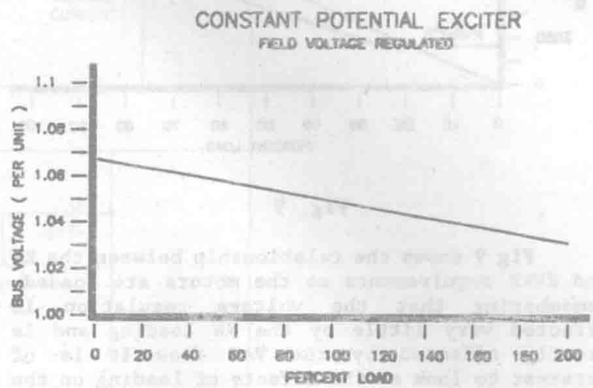

Fig. 7

The var flow is about the same with less rise on unload and less droop when the motor loading. There is no stability issues with the brushless motors.

DC FIELD CURRENT REGULATED:

The DC Field Current Regulated exciter has a voltage regulation curve the same as the Constant Potential Regulated supply except the warm up period is eliminated. It has advantages in systems where high impact loads are likely to occur and it is desirable to field force prior to the event. The field forcing can be well above full field for a short time say 125 % for 1 Minute without damage to the exciter or the motor.

POWER FACTOR REGULATED EXCITERS:

Lets investigate the effects of power factor regulation on the power system. The first assumption is that the power factor being regulating is that of the motor and not the power system.

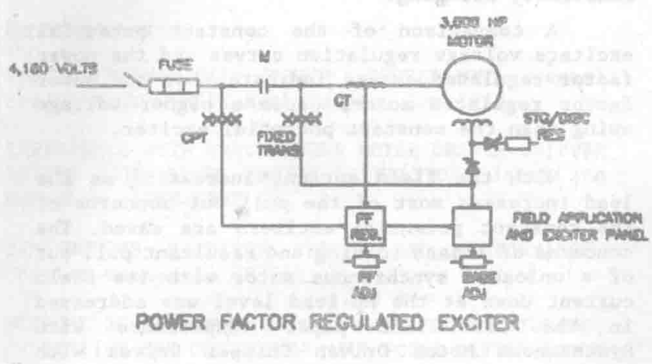

Fig. 8

Figure 8 shows the single line for a power factor regulated motor.

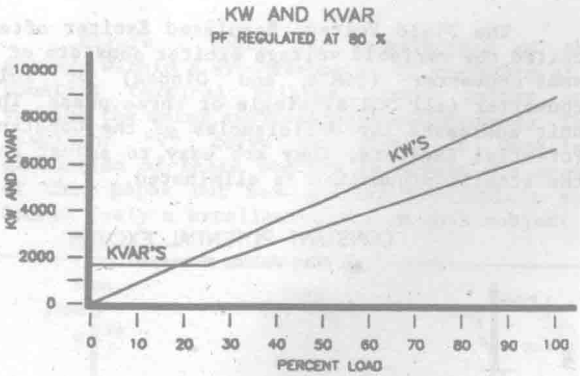

Fig. 9

Fig 9 shows the relationship between the KW and KVAR requirements as the motors are loaded. Remembering that the voltage regulation is affected very little by the KW loading and is greatly affected by the VAR flow it is of interest to look at the effects of loading on the voltage regulation of our typical power system.

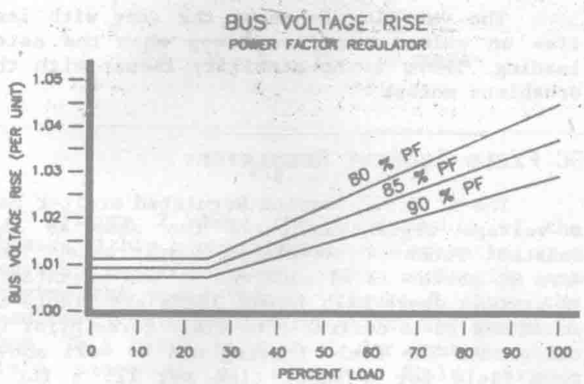

Fig. 10

Fig. 10 shows the relationship between Motor Load and Motor Terminal Voltage in the typical system. This assumes the power factor regulator is set up for 80%, 90% and 95% operation. Power factor regulators sound good except where load swings are a constant: there fore the var flow and system voltage are constantly swinging.

A comparison of the constant potential exciters voltage regulation curves and the power factor regulated curves indicate that the power factor regulated motors cause a higher voltage swing than the constant potential exciter.

With the field current increasing as the load increases most of the pull out concerns of the constant potential exciters are eased. The concerns of impact loading and resultant pull out of a unloaded synchronous motor with its field current down at the no-load level was addressed in the 1990 IEEE paper "Experience with Synchronous Motor Driven Chipper Drives with Power Factor Regulation" Jones and Hamilton.

Var Regulated Field Exciters:

Fig 11 shows the single line for a Var regulated controller in a E2 motor starter.

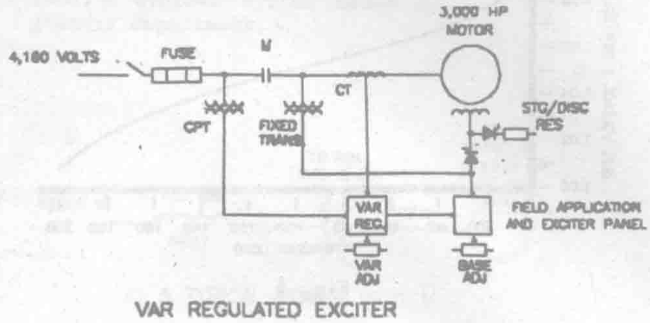

Fig. 11

We have seen that the voltage fluctuations are due to the swinging of var flow in the power system. Fig 12 Shows how regulating the motor Var output over its load range eliminates this voltage swing. To be sure the motors coming on line would increase the power system voltage but the Generator Voltage regulator and load tap changers compensate.

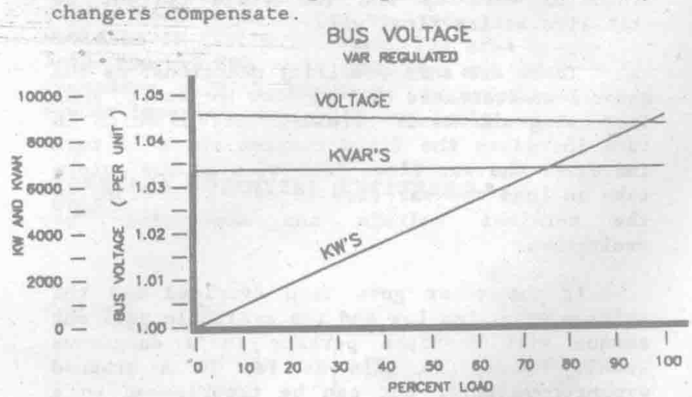

Fig. 12

With the motor field current well above the no-load level the concerns of impact loading are eliminated. The Field Forcing on transient overloads is similar to the Power Factor Regulated Exciters. However the motor field starts from a higher level.

A Plant Wide Application:

Control of the individual var output of synchronous motors solves some of the mill system voltage problems. However there are long term plant load changes such as Finish Mills going down, quarry operation and normal maintenance shutdowns that make it desirable to change the profile of the power system.

With the modern data gathering systems similar to the one discussed in the 1990 IEEE paper "Networking Communication for Power Monitoring, Protection and Control of Mill Power Distribution" Krug and Quayle, makes it possible to adjust the reference of the individual synchronous motor to meet the needs of the total mill power