INNOVATIVE INTEGRATED DC-FED MOTOR-CONVERTOR SOLUTION FOR MINING CONVEYORS

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Abstract – Conveyors are the efficient way to transfer excavated material from the mines to the process industry. Direct drive technology in conveyors eliminates mechanical transmission elements in the system and enables compact motor designs. This paper includes state of the art active stator machines with drive inside the motor. The first part of the paper presents the conventional motor drive system. The second part of the paper describes a demonstrator concept of an integrated motor-convertor solution which is under testing where the power electronics are integrated into the stator enabling polyphase functionality and coil redundancy during fault scenarios. The motor-converter arrangement allows the drive units to be operated by a DC grid as against conventional AC supply that results in reduced cabling and losses along with the reduced overall space impact. The third part of the paper presents the proposed motor-convertor as an inside out rotor design solution for conveyor applications, addressing the design constraints, high torque density requirement with shorter service times and reduced maintenance requirements as a compact package.

Index – Conveyor, Axial flux motor, Convertor, Active stator, AC, DC, Polyphase, Power Electronics.

I. INTRODUCTION

Conveyor belts have been in existence for over 100 years and employed in many industries to continuously convey components, products, medicines, foods, raw materials etc. from one location to another. The size and type of drive for the conveyer belt was, is, a function of the load requirements (start-up, maximum operational and fault conditions), the environment and maintainability. With a focus on the mining conveyor applications, for many years conventional radial flux ac synchronous electrical machines have provided the mechanical means for belt pulley/barrel rotation. Geared solutions were the arrangements of choice, to be a competitive and practical arrangement. A high-speed synchronous electrical motor coupled to a speed reducing gearbox with the output connected to the conveyor belt's barrel. The geared arrangement allowed the high torque and low speed belt operation to be accommodated and controlled. The electrical motors required the supply of ac electrical power. To enable operation and control of the motors the ac power supply would be directed to a cabinet structure containing breakers, transformers, drives and other conditional monitoring hardware and services control. The cabinets may occupy floor space in a building enclosing, or close to, the belt drives, but away from built and occupied structures. E-houses were needed to secure and protect the cabinets. For each belt drive location there was a real estate cost due to the footprint of the cabinet structures/E-houses, motor, step down gearbox, conveyor barrel and the cable support architecture (Fig.1).

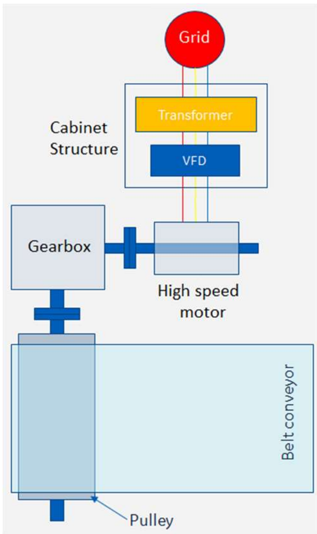

Fig.1 Simple Illustration of a Geared Drive Arrangement

Conveyor belts operated across great lengths and required end station and mid-station units to provide sufficient drive capability for the load being transported. Longer belt lengths were offered, due to the demands of the industry, and so the cabling requirements grew. Mines and quarries are typically located away from populated areas and away from power grids requiring cable runs of great length or the presence of local power generation units. Sending AC electrical power distance using cable introduces losses, that is paid for in the operating costs. To mitigate these operating losses/costs dc cables have been used, and here there was a different cost to consider, the requirement for rectification of the ac power to dc and then a frequency inverter to recreate the ac supply. The cables losses are reduced but there is additional hardware for containment in the cabinet/E-house structure requiring foundation support. CAPEX and OPEX assessment are performed to determine the optimum arrangement.

Enhancements in materials, improved design tools and the push for lower cost products more easily maintained was the catalyst to improve conveyor drives. The availability and introduction of such materials as high strength magnets enabled the expansion of the synchronous electrical motor range into high torque at very low speed. Permanent magnet motors became the thrust in moving from a geared drive approach to gearless drive with a motor coupled directly to the barrel [1] [2]. This configuration eliminated the cost of the speed reduction gearbox, reduced the size of the foundation structure and simplified maintenance tasks; a cost saving to the customer. The magnitude of the savings was reduced due to the cost of the new slow speed, direct drive high torque motors but CAPEX and OPEX savings were made (Fig. 2).

The push for improvements remained and was the basis for further conveyor drive enhancements. A compact version was created where the motor and conveyor structures were merged reducing the number of bearings required [1]. This again reduced the cost of the product, the foundation structure and the maintenance requirements. Further CAPEX and OPEX savings were had (Fig.3).

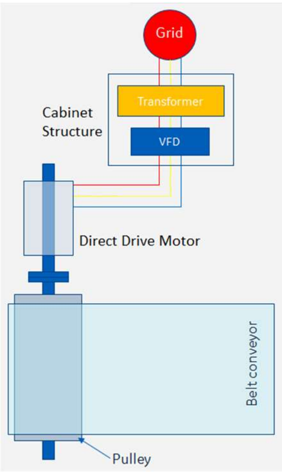

Fig. 2 Gearless drive arrangement

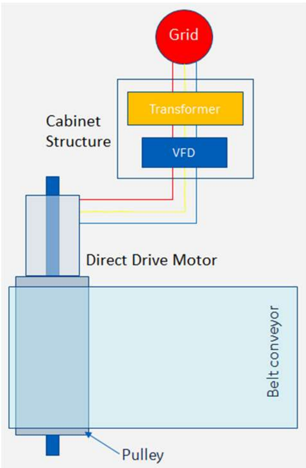

Fig. 3 Compact gearless drive arrangement

Has the conveyor drive reach its final design iteration? Minimal bearings, compact motor and barrel structure with reduced foundation requirements. Is it possible to go further with this product?

II. THE NEXT REVOLUTION: ACTIVE STATOR

A. DC Motor with Rotor Commutator

Thomas Davenport invented in 1834 the first practical direct current (DC) electric motor. In 1879, Thomas Edison [3] improved electric generator or motor with better efficiency in the commutator design, making it more suitable for practical applications (Fig.4). Due to the problem of transporting energy over long distances and the wear of brushes in DC machine collectors, Nikolas Tesla and Mikhail Dolivo-Dobrovolsky developed in 1889 the first 3-phase AC squirrel-cage asynchronous machine whose rotor did not require an electrical connection. The induction machine, however, has larger active parts (stator and rotor) than the DC machine.

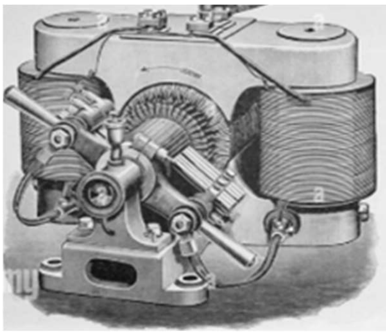
Fig. 4 Edison's DC Generator with rotor commutator

B. Active Stator with GTO Commutator

A century later in 1982 with the possibility of using power diodes, Parker [4] and Thornton [5] imagined a concept of a machine with an electronic commutator on the stator, named active stator. If reliability, redundancy, and the ability to keep operating is paramount, as well as compact and with a smaller footprint, then the new Active Stator machines could be a serious consideration. These machines overcome the limitations but employ the benefits of brush commutated DC machines.

In the early 2000s, Crane [6] [7] developed a concept of DC electrical machine with a large number of phases. The machine includes a rotor and a stator assembly. The rotor has Np rotating field poles. The stator has Ns winding slots, where Ns/Np is a non-integer ratio. A stator winding includes a plurality of coils received in the winding slots and defines a plurality of stator phases. A power electronic switching assembly includes first and second DC load terminals that can be connected to external equipment and a plurality of switching modules (Fig.5). Each switching module includes power electronic devices and is connected to a respective stator coil. A first proportion of the switching modules are connected together in series between the first and second dc load terminals and a second proportion of the switching modules are connected together in series between the first and second dc load terminals to define two parallel dc circuits (Fig.6).

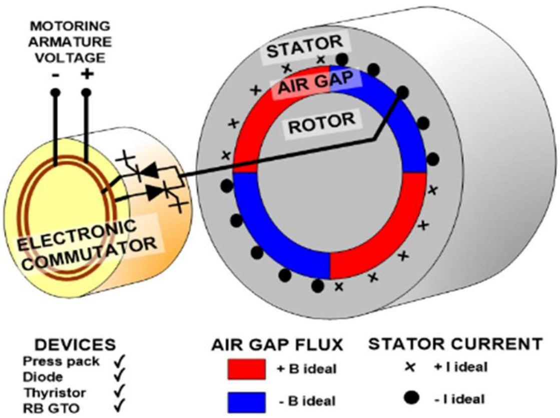

Fig. 5 Active stator concept with electronic commutation

The objective of this work is show how a remotely located gate driver could be connected to a Gate Turn Off Thyristor (GTO) to allow unity gain turn off to be exploited within the proposed electronic commutator. The GTO is snubber assisted, and unity gain gate turn off modes are described with reference to the classical “two-transistor” model of the thyristor. A novel low inductance arrangement for connecting a remotely located and compact gate driver to the GTO wafer is described. This arrangement allows the desired axial flow of a liquid dielectric coolant over a compressed “stick” stack of GTOs.

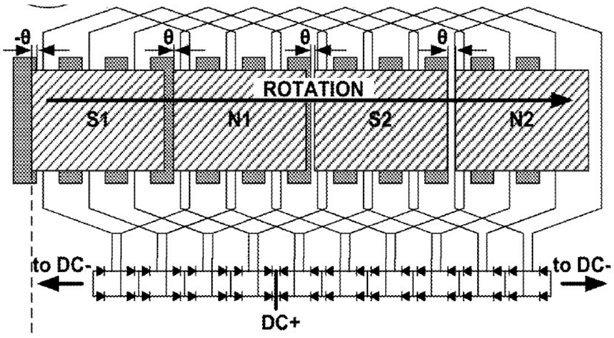

Fig. 6 Winding with power electronic integration [6]

A demonstrator was tested in 2010 at 15MW, Midel oil-cooled in the coils with a GTO-based commutator. It was a back-to-back (B2B) system test during which the two halves of the tandem machine were tested simultaneously and in conjunction with a full set of control and auxiliary units (Fig. 7 and Fig. 8). The rotors were wound salient poles connected to a rotating rectifier and exciter system.

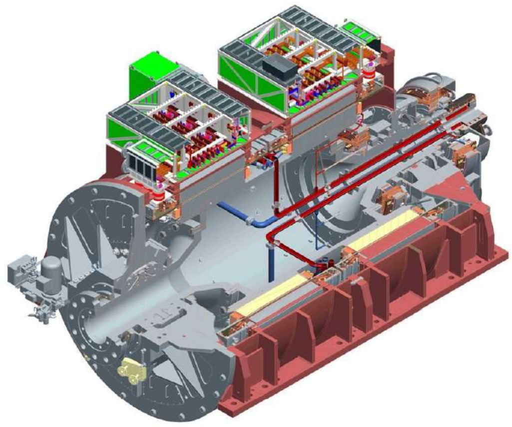
Fig. 7 15MW tandem active stator general arrangement [6]

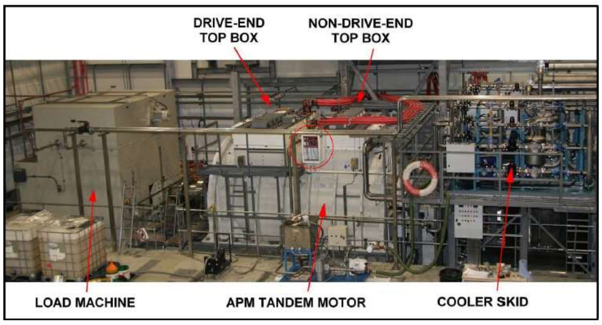

Fig. 8 General load test arrangement @ 2010

After these tests, it was clearly demonstrated a differentiation in higher power densities to footprint with component integration savings coming from fusion of motor and converter, elimination of cabling between motor and converter, sharing of cooling system. The identified benefits included:

- Trapezoidal Back-EMF for Max. Torque/Amp
- High torque density & efficiency
- Applicable to any AC motor – PM, Induction
- Low converter switching loss due to low frequency
- Machine is fed by DC source
- Many electronic modules are employed – Greater redundancy
- Ultra-High Availability
- Graceful degradation of operation under module faults down to the individual switch/comm segment level

C. Active Stator with SiC MOSFETs Commutator

Following the promising feedback from this first demonstrator, the decision was made to develop a new, more efficient and practical demonstrator by replacing the GTO commutator with a SiC MOSFETs commutator, and the wound rotor poles with permanent magnet poles. The classical drive and motor arrangement (Fig. 9) is replaced by an integrated active stator machine (Fig.10), with the pertinent benefits highlighted.

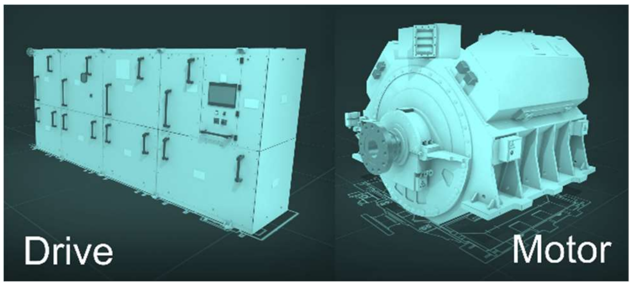

Fig. 9 Classical Drive & Motor Arrangement

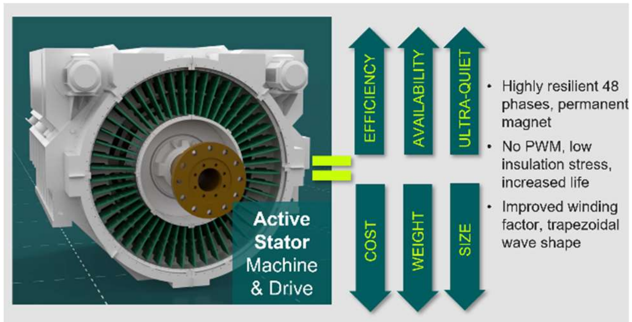

Fig. 10 Active stator machine arrangement @ 2023

Unlike many machines on the market, including some which have tried to mount power electronics on the machine, the active stator is a true DC machine, it does not have 3 or 6 phases, and does not use a sinusoidal waveform. It uses a trapezoidal DC waveform, which produces more torque, so the machine can be smaller. The demonstration machine has no more windings(coils) than a normal machine, (in fact the stator is 90% standard), but the machine is not arranged as 3 or 6 phase, but is actually polyphase, 48 phases in fact, all of which can be individually controlled. This makes it extremely smooth, quiet and resilient, with a huge amount of graceful degradation with the machine able to isolate internal faults, self-heal and continue running If any of the 48 phases are lost. The power electronics do not create a PWM (Pulse Width Modulated) wave form, so they do not have a high switching frequency with associated higher switching losses and reduced machine insulation life like current PWM drive solutions. The power electronics are distributed around the machine and connected to each coil, and unlike existing solutions, do not require large external drives, with sine wave or dv dt filters, this saves both space, cooling and cabling.

This technology allows a step change in redundancy and graceful degradation. A normal 3-phase machine/drive has no graceful degradation on a fault, if there is a problem in the machine or its associated convertor 100% of the system is lost. Sometimes a conventional system uses a “dual wound” machine, where there two sets of three phases, on these machines only 50% of the system is lost on a fault. On an active stator machine, typically there may be 48 phases, all of which can be operated independently, giving a huge amount of redundancy and resilience. If there is a fault in a coil or in a power electronic device, then only one phase out of 48, or 2% of the machine output is lost. (Fig. 11) shows the stator and end rings of a conventional “Dual Wound” 6 phase machine.

Fig. 11 Dual wound 6-phase machine stator

End rings are circular conductors located and supported at one or both ends of the machine, fed by AC or DC and used to distribute the power equally to all the stator coils connected to it, equivalent to a ring manifold in a fluid system. For high availability applications, this can be a game changer, as first fault loses 2%, second fault loses 4% of output etc. In many applications, it is expected that if a single phase is lost, then the machine and the system simply carry on running and the failed component is easily replaced at the next maintenance period.

The 48 phases add no complexity to the machine construction, as there are no more coils than in a standard machine, of the same size and rating. The stator laminations and coils making up the core pack are identical to the 3-phase machine, just conductors and iron, with no exotic materials or cooling mediums within the machine, it is simply CACW for the machine and direct water cooling for the electronics. The only difference is in the end windings which have power electronics between the coils and the end rings.

(Fig. 12) shows a simplification (single line diagram) of a 3-phase machine with four end rings, 3-phase and neutral, where all the end windings are brazed to the end rings, and any single point failure results in loss of the machine.

The difference with an active stator machine is shown diagrammatically in (Fig. 13). End windings refer to the collection of and braced array of the coil sections located outside the laminated core. The U,V,W, (and N) end rings that are present on the end of all AC machines are repurposed as a pair of DC rings, which feed the power electronics. Each element can be switched in or switched out for efficiency or if there is a failure. With 48 phases there are now effectively 48 little machines on a common DC bus.

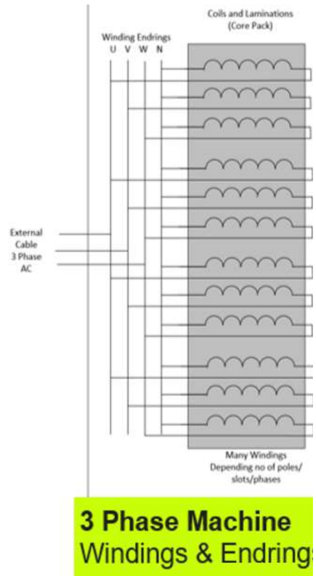

Fig. 12 Single line diagram of conventional stator 3-phase machine

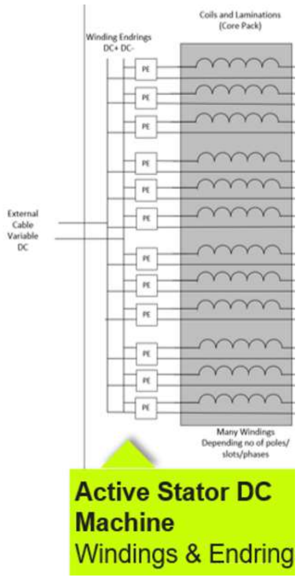

Fig. 13 Single line diagram of active stator 3-phase machine

The power electronic “coil drivers” for each coil are housed in multiple identical modules around the periphery of the airgap. These modules, as well as the end rings are all fitted within the end winding space. These modules, approximately the size of a laptop, and weighing around 7kg incorporate the low loss silicon carbide MOSFETs, the water cooled heatsink as well as low level controls and the other passives. Whilst the normal user interfaces are present, the actual real time functioning of the electronics can be observed visually by viewing the LED status lights around the periphery of the air gap. With the coil drivers physically located at the torque producing positions, the real time operation, and location of torque at any instant can be seen visually for the first time directly on the machine.

The coil drivers are fully detachable and removable from the machine enabling inspection, interrogation, repair or replacement as required. If there is a problem in any individual coil driver, it is immediately shown, including its location via the lights, but is automatically bypassed, with the machine continuing in operation with only a 1/48 or 2% reduction in torque. Notwithstanding the ease of fault diagnosis, repair and self-healing ride through, with the machine switching at Hz, rather than kHz, the switching losses are much lower and the device reliability much higher. The cables between the convertor and motor are also of course included internally within the machine. This is a true DC machine, with a permanent magnet rotor, there are no AC waveforms, there is no PWM (pulse width modulation) switching required to synthesize a sine wave. The machine, therefore, has no PWM high frequency noise or switching losses or dV/dT insulation stress. (Fig. 14) shows a section of a multimegawatt active stator machine on test, the lights give an instant diagnosis if there is a problem (green goes to red), so visual diagnosis of the machine and convertor is possible, as well watching real time operation of the machine, switching blue when torque is applied to those windings.

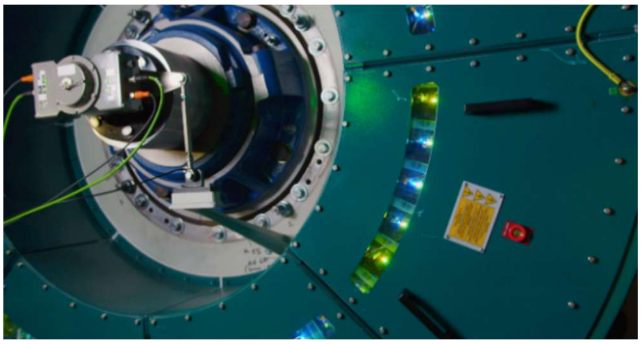

Fig. 14 Multi-megawatt active stator machine on Test @ 2024

Modern Active Stator machines are normally coupled with permanent magnet rotors but can engage with any rotor design. They can be applied to almost any stator in classical use, when high availability, resilience and redundancy is required for the process, with ride through on faults, and where there is a desire to reduce convertor spaces, cooling and cabling. The Active Stator machine is more than a theoretical possibility, the demonstration machine exists and has been/is being tested. The performance characteristics are impressive, exceeding expectations. Active Stator machines may well be the future for many markets, including remote based conveyor drive motors. Additional photo of the motor on test is shown in Figure 15. The actual test performed so far include:

- Coil Driver PE, Current and Voltage Bench Testing,
- Uncoupled Running,
- Coupled Running,
- Full Speed,
- Heat Run @ Full current,
- Running on single and dual rings,
- Uncoupled Losses.

Fig. 15 Active stator machine on test @ 2024

III. AXIAL MOTOR DESIGN

Axial-flux motor (AFM) is the most attractive technology in many applications, such as automobile, marine and other industrial applications. The attractive feature of the AFM is due to compact structure, high torque density, and high-power density with less active material. Compared with the conventional radial-flux motors, AFM can be used where there is a higher power requirement in a shorter footprint. Axial-flux motor have a different topology [8]. The single-stator single-rotor (SSSR) motor is the simplest configuration. However, the axial force between the rotor and stator is very high in SSSR. To mitigate the axial force, the double stator single rotor (DSSR) motor was proposed for this application. The design study shows the flux path pass through the rotor. A 2D model of a double-sided stator single-rotor (DSSR) AF motor is presented in (Fig. 16).

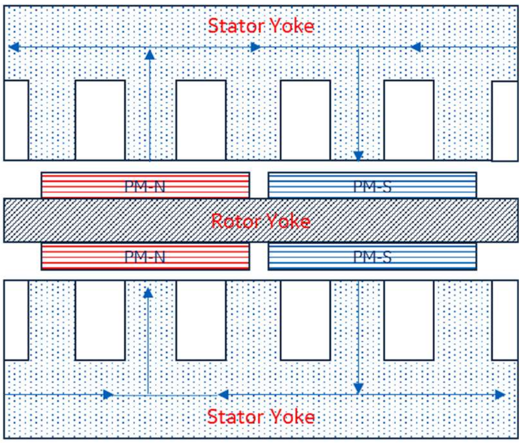

Fig. 16 2D flux flow path of a double stator single rotor (DSSR)

A. Benefits of Axial-Flux Topology

In addition to being a more compact motor, AFM offers many advantages over radial-flux machines [9] [10]:

- Lightweight construction
- High power density
- High torque-to-weight ratio
- Increased energy efficiency
- Reduced raw material usage
- Greater design flexibility.

There are many applications where AFM can be used; this paper is focused on mining conveyor applications where the integrated solution can be utilized for increased efficiency, and easier remote installation and maintenance. The gearless direct drive conveyor principle was expanded further so that the motor, pulley and convertor were combined in such a way that the complete drive becomes an integral part of the conveyor system. AFM currently lacks production technology and machinery that creates higher production costs. Mechanical and technical challenges in maintaining uniform air gap between the rotor and stator are mitigated with special design features. Despite the challenges, AFM has benefits over radial flux motors in conveyor applications. The comparison of radial vs axial is shown (Fig. 11).

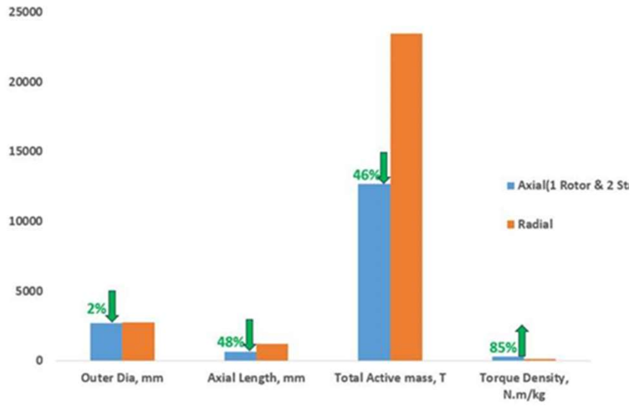

Fig. 17 Comparison of radial & axial flux motors

B. Conveyor drive technology description

The gearless drive technology concept was developed for overland long-haul conveyors. A double end integrated axial flux permanent magnet direct drive AC motor [1] [2] was proposed as an expanded version using Active stator technology.

C. Direct Drive Conveyor solution

Using the inside out design approach for the motor with integral convertor, the construction of a high-torque high-efficient Axial flux permanent magnet drive system is intimately connected to the pulley (Fig. 18). This motor produces the required output power, mechanical torque and power factor.

The power required at the driving pulley in conveyor system is calculated with the peripheral force on the pulley [11] with expression 1 and 2:

$$T_E = R + R_s + R_{sp} + R_{SL} \qquad (1)$$

$$P_{DP} = T_E \, X \frac{V}{1000} \qquad (2)$$

where TE (N) is the Peripheral force, R (N) is the main resistance, R_s (N) is the secondary resistance, R_{sp} (N) is the special resistance, R_{SL} (N) is the slope resistance. PDP is the power at drive pulley, V (m/s) is the belt speed.

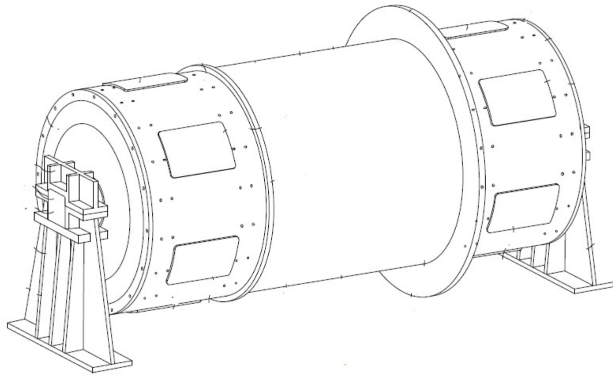

Fig. 18 Integrated gearless conveyor drive

The motor requirement is estimated considering the efficiency of the drive pulley. As a case study and development, the following drive parameters of the belt conveyor were chosen (Table I). The integration of motor-pulley arrangement eliminates the large expensive foundations for the equivalent motor and separate convertor.

TABLE I
CONVEYOR DRIVE REQUIREMENT SPECIFICATION

Parameter	Direct Drive Gearless Solution
Power	2 MW
Voltage	3.3 kV
Rated Speed	50 rpm
Torque	380 kN.m
Pulley Width	2 m
Pulley Diameter	2 m
Reliability & Availability	Powertrain MTBF = ~25 years+
Efficiency	Average Powertrain System Efficiency 94% (For a typical 2MW Conveyor 5% increase in Efficiency saves 4GWhrs energy consumption)
Safety	Gearless removes mechanical components risk Convertor technology removes AC supply fault failures
Maintenance	Minimal – occasional inspection, some maintenance checks for motor bearings
Cooling	Closed circuit advanced water (or air) cooling
Insulation	Class F insulation as standard
Quality & Performance	No gearbox Dead-band which improves performance and reduces noise

D. DC-Fed Conveyor Drive System

The conveyors used in mines runs for long distance in kilometers, the motor drives are used at multiple stations to drive the belt. These motor drives are powered by long AC cables from Variable Frequency Drives (VFD), this in turn increases the cable cost, losses and voltage drop etc. To mitigate the technical challenges, the proven and tested technology of active stator technology is expanded for mining application where the Medium Voltage (MV) drive is split into convertor and inverter modules. The convertor module is placed close to the Grid. The Invertor module, described in section II, is embedded inside the motor behind the stator poles (Fig.19) and is connected to each stator pole coil inside allowing the motor to behave as a polyphase machine. Even if some stator poles fail during operation, the motor will continue to deliver a slightly derated power without halting the conveyor system. A single convertor controls the head and tail pulley motors, and these motors are energized by a DC supply by long run cables from the convertor module (Fig. 20).

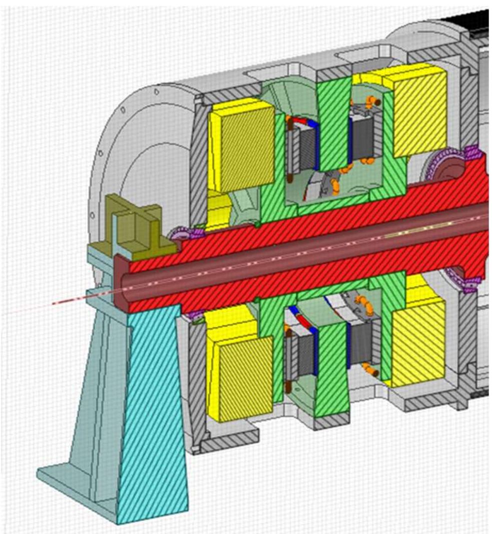

Fig.19 Axial flux motor with integrated invertor

A theoretical evaluation was performed on a conventional AC drive system with DC fed conveyor drive system based on Voltage drop, cable cost and losses.

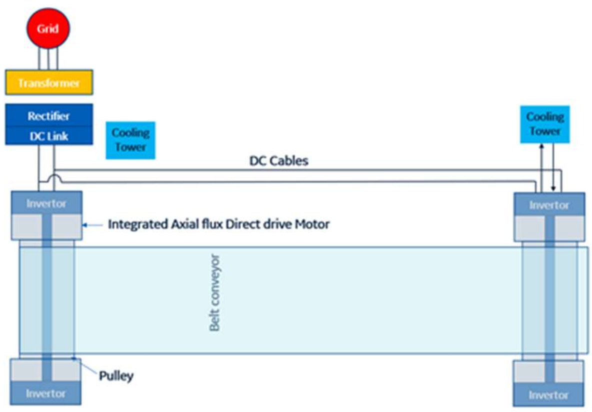

Fig. 20 Long haul conveyor drive system architecture

E. Performance and Cost saving

An AC system uses 3 cables from the VFD to the motor, if 2 motors are connected to the same VFD, the farthest motor experience a common problem of voltage drop [12]. The size of the cables is calculated as per the requirement. The voltage drop in the cable is defined as a decrease in the voltage on the motor. The voltage drop ΔV_{ac} in A.C cables and ΔV_{dc} in DC cables are estimated by the expressions 3 and 4.

$$\Delta Vac\ (\%) = \frac{kLI_n\left(\frac{R_{ac}}{CP}\cos\varphi + \frac{X_L}{CP}\sin\varphi\right)}{V_N}\ X\ 100 \qquad (3)$$

$$\Delta Vdc\ (\%) = \frac{2\,kLI_n\,R_{dc}}{V_N}\ X\ 100 \qquad (4)$$

where I_n (A) is the nominal current, L (m) is the circuit length, R_{ac} (Ω/m) is the AC resistance per unit length, R_{dc} (Ω/m) is the DC resistance per unit length, X_L (Ω/m) is the Reactive inductance per unit length, cos(φ) is the Power factor, sin(φ) is the Reactive factor, V_N (V) System voltage, ΔV_{ac} (%) is the Alternating current voltage drop, ΔV_{dc} (%) is the Direct current voltage drop.

The acceptable limit of voltage drop as per IEC 61000-4 is maximum of 5% for >1kV, it is understandable that, referring to Figure 21, longer the length of the conveyor, the AC system does not meet the acceptable limit. AC system requires booster transformers or reactive power equipment at different locations in conveyors system. Whereas DC system shows less voltage drop and less likely to require additional DC-DC booster equipment.

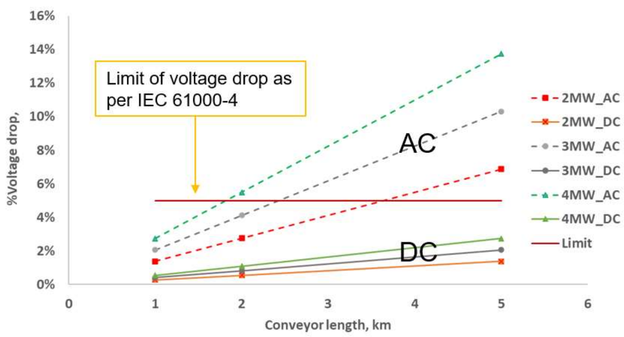

Fig. 21 Voltage Drop Comparison

The cables are sized to withstand the fault condition during installation and operation. The short circuit capacity criterium is used to determine the minimum cross-sectional area of the cable with expression 5.

$$A = (I_{sc} * \sqrt{t})/K \qquad (5)$$

where A (mm^2) is the cross-section area of cable, I_{sc} (A) is the short circuit current, t (s) is the operating time of disconnecting device, K is the constant.

There is a significant reduction in the cable cost, as DC system uses less cables and conductor cross section is less thereby approximately 30% saving in CAPEX. The losses in AC system are higher due to VFD and skin effect and is approximately 15% higher than DC fed system.

IV. CONCLUSIONS

This paper provides a vision of how to expand the active stator technology into mining applications for long-haul conveyors where power delivery, motor maintainability, reliability, redundancy and resilience are of paramount importance. This technology is proposed in gearless conveyors as an integrated axial flux motor with convertor system inside the belt pulley. The real estate cost comes down due to the reduced footprint of the cabinet structures/E-houses, motor and the elimination of the step-down gearbox. The DC fed technology leads to improvements in power delivery, reduced cabling and losses providing additional benefits to the user. The next advance in long haul conveyor drive systems is here now with the introduction of axial flux motors with active stator technology, leading to reduced CAPEX and OPEX.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1]. A.P. Loganathan, A. Ramasamy, H. Mirahki, S. Tholasingam, “Gearless conveyor drive”, Patent PCT/EP2024/056167, 2024.
[2]. A.P. Loganathan, A. Ramasamy, H. Mirahki, S. Tholasingam, L. Durantay, Ch. Galmiche, “Gearless conveyor drive”, Patent EP 24179084, 2024
[3]. Th. Edison, “Electric Generator or Motor”, US Patent No. 242901, 1881.
[4]. L. Parker, “Electronic commutation for direct current electric motors”, Patent. GB2117580, 1982.
[5]. R. Thornton, “Electronic commutation system for motors”, Patent. US3619746, 1984.
[6]. A.D. Crane, “The Adaptation, Operating Modes and Integration of the Reverse Blocking GTO within Multi-MW brushless DC Machines”, Thesis of the University of Nottingham, July 2015.
[7]. A.D. Crane, “DC Electrical Machines”, US Patent 9252645, 2017.
[8]. Zhuo Hao, Yangyang Ma, Pengyu Wang, Geng Luo, and Yisong Chen, A Review of Axial-Flux Permanent-Magnet Motors: Topological Structures, Design, Optimization and Control Techniques.
[9]. Z. Zhang, F. Profumo, A. Tenconi, “Axial-flux versus radial-flux permanent-magnet motors”, in Electromotion Journal, 1996, vol 3, 134-140.
[10]. A. Cavignino, M. Lazzari, F. Profumo, A. Tenconi, “A Comparison between the Axial Flux and the Radial Flux Structures for PM Synchronous Motors”, in IEEE Transactions on Industry Applications, vol 38, No. 6, Nov/Dec 2002.
[11]. ISO 5048: 1989 Continuous mechanical handling equipment - Belt conveyors with carrying idlers - Calculations of operating power and tensile forces
[12]. IEC 61000-4 Measurement accuracy.

VII. NOMENCLATURE

P	Power (MW)
N	Speed (rpm)
d	Pulley diameter (m)
l	Pulley Length (m)
ΔV_{ac}	AC voltage drop (V)
ΔV_{dc}	DC voltage drop (V)
L	Circuit length (m)
R_{ac}	AC resistance (Ω/m)
R_{dc}	DC resistance (Ω/m)
X_L	Reactive inductance(Ω/m)
$\cos(\varphi)$	Power factor
$\sin(\varphi)$	Reactive factor
T_E	Peripheral force (N)
R	Main resistance (N)
R_s	Secondary resistance (N)
R_{sp}	Special resistance (N)
R_{SL}	Slope resistance (N)
P_{DP}	Power at drive pulley (W)
V	Belt speed (m/s)
I_n	Nominal current (A)
V_N	System Voltage (V)
A	Cross section area (mm²)
t	Operating time (s)
I_{sc}	RMS short circuit current (A)

AC	Alternating Current
AFM	Axial flux Motor
DC	Direct Current
DSSR	Double Stator Single Rotor
GCD	Gearless Conveyor Drive
GTO	Gate Turn Off Thyristor
MOSFET	Metal Oxyde Semi-Conductor Field Effect Transistor
MV	Medium Voltage
PWM	Pulse Width Modulation
SiC	Silicon Carbide
SSSR	Single Stator Single Rotor
VFD	Variable Frequency Drive

VIII. VITA

Arun Prasad LOGANATHAN holds a master's degree in mechanical engineering and has 18+ years' experience in the design and development of Motors & Generators. He is also expert in FEA, CFD and Rotor dynamics. He has led the design and development of projects. He presently holds 4+ patent. He is currently Senior Engineer within GE Vernova Power Conversion & Storage with special focus on innovative electrical machines technologies.

Lionel DURANTAY is graduated from the Ecole Nationale Supérieure d'Electricité et de Mécanique (ENSEM) in Nancy, France with an engineering degree in 1989 then passed PhD in 1993. As R&D Leader, he has developed innovative variable speed electric systems for Oil & Gas, air separation, onshore & offshore renewable, marine and navy businesses. He has authored or coauthored 58+ electromechanical papers, and supervised 6+ doctorates. He presently holds 30+ patents. He is 6-sigma Master Black Belt. He teaches statistical process control and design for 6-sigma at the University of Lorraine since 2005. He received GE's Thomas Edison Award in 2013 for technical excellence and customer impact. He is currently Chief Consulting Engineer & Global Product & Technology Leader within GE Vernova Power Conversion & Storage with special focus on developing full electric compression.

Nicholas SMITH has more than 37 years power system design experience in mining, marine and renewables, He has an Honors Degree in Electrical and Electronic Engineering, is a chartered engineer, and a Fellow of the Institute of Engineering and Technology. His main role is taking rotating machines, power electronics, automation and control and integrating them into power system solutions for customers. Actively involved from patents and concepts all the way through to design support in the field. He is currently a Global Product and Technology Executive within GE Vernova Power Conversion & Storage with special focus on developing active stator technology.

Michael HAGUE holds a Bachelor of Science Degree in Mechanical Engineering and has over 40 years' experience in the design, development and troubleshooting of electrical machines on test beds and at global installation locations. He is an expert in FEA and rotor dynamics and has led the design and development of special electrical machines. He presently holds 3+ patent. He is currently a Principal Engineer for GE Vernova Power Conversion & Storage with special focus on rotating machines.