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## **Selecting the Optimised Pump Configuration and Drive Option for the Condensate Extraction and Boiler Feed Pumps for the New Eskom Supercritical Power Stations**

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*Eskom has embarked on a major Capital Expenditure program to cater for the growing demand for power as a result of a rapidly developing South African economy. Future developments include electrical power generation utilizing diverse technologies such as: fossil, nuclear, pebble bed modular reactors, hydro, open gas cycle, combined cycle, wind, and solar energy.*

*The first two new supercritical fossil fired power stations, Medupi (6 units, each 650 MW) and Kusile (6 units, each 800 MW) are presently in the design and construction phase. The condensate extraction pumps and boiler feed pumps are amongst the highest consumers of auxiliary electrical power within a power station, it is therefore of utmost importance that the correct optimized pump configurations and drive options for each of these pumps is selected.*

*The paper describes how the final selection of the condensate extraction pumps for the two new supercritical power stations was made. The option of a vertical vs. a horizontally positioned pump, utilizing an air cooled condenser was considered. Each condensate extraction pump is sized for 100% bypass operation. The paper discusses why two 100% duty pumps were selected with one being variable speed electrical motor driven and the standby one fixed speed electrical motor driven.*

*In order to achieve the required high plant availability, a 3–50% boiler feed pump configuration per unit will be utilized at the two new supercritical power stations.*

*The paper also discusses four different variable speed boiler feed pump drive options that were available for selection.*

*The details of each variable speed drive option are included and discussed. The final decision in selecting the optimized boiler feed pump drive was based on an economic evaluation model that included three different modes of operation, i. e. (base load, load following, and two shifting), initial capital cost and auxiliary power consumption as based on boiler feed pump set efficiency over the expected 50 year life span of the power station.*

**Key words:** *Eskom, supercritical fossil power station, condensate extraction pump, boiler feed pump, variable speed drive*

## INTRODUCTION

In Southern Africa, the electricity supply industry is dominated by South Africa's state-owned utility, Eskom\*. It operates 17 coal-fired power stations in the country and, including its hydropower, nuclear, and gas turbine stations, has a generating capacity of 39 000 MW. Eskom supplies 90% of the electricity used in South Africa, generates around two-thirds of the electricity produced in the whole of Africa and is extending its transmission grid north into neighboring sub-Saharan countries [1].

The current electricity usage for South Africa is 35 000 MW for morning peak and 36 000 MW for evening peak. The peak power demand is during the winter months in South Africa.

Eskom has embarked on a major capital expenditure program to cater for the growing demand for power as a result of a rapidly developing South African economy. Future developments include electrical power generation utilizing diverse technologies such as: fossil, nuclear, pebble bed modular reactors, hydro, open gas cycle, combined cycle, wind, and solar energy.

The first two new supercritical fossil fired power stations, Medupi (6 units, each 650 MW) and Kusile (6 units, each 800 MW) are presently in the design and construction phase.

The condensate extraction pumps and boiler feed pumps are amongst the highest consumers of auxiliary electrical power within a power station, it is therefore of utmost importance that the correct optimized pump configurations and drive options for each of these pumps is selected.

The paper discusses the selecting of the optimized pump configuration and drive option for the condensate extraction and boiler feed pumps for the new Eskom supercritical power stations.

## CONDENSATE EXTRACTION PUMPS

### Condensate extraction pump configuration

The following condensate extraction pump (CEP) configurations were considered:

- 2 100% duty pumps, one in operation and one 100% on standby (Eskom standard), and
- 3 50% duty pumps, two in parallel operation and one 50% on standby.

When comparing the two CEP configurations the following was considered:

- initial capital costs,
- piping and instrumentation, including valves,
- electrical cabling and systems,
- space required for installation,
- redundancy, and
- spares holding.

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\* Eskom is the South African power utility. It is the fifth largest electrical utility in the world and supplies 90% of South Africa's power and two thirds of the power generated on the entire African continent

As determined by an economic evaluation using all factors as stated above, it was concluded that a 2 100% duty CEP configuration would be the optimal CEP configuration for the expected 50 year life span of the power station.

#### **Condensate extraction pumps installations in smaller and older Eskom power stations**

All existing Eskom power stations utilize a 2 100% CEP configuration. The older type power stations that don't have any main turbine bypass systems utilizes two fixed speed CEP's with their design point the same as the turbine maximum continuous rating (TMCR) duty point.

The condensate flow of the CEP is controlled by throttling the main condensate control valve. The CEP's installed at the power stations with an output of less than 350 MW are all fixed speed horizontally arranged CEP's. The pumps are horizontally split casing designs with a double entry suction impeller. Depending on the flow and head requirements, the pumps could be single, two or three stage design. The pumps all run at 6 pole speed ( $N = 980$  rpm). The slow speed and double suction impellers are specifically considered in order to satisfy the NPSH requirements of the pumps and due to the low NPSH available from the condenser hot-well.

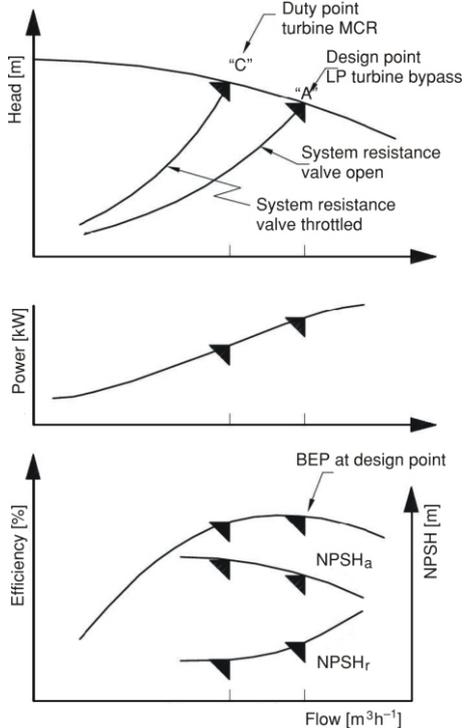
#### **Condensate extraction pumps installations in newer larger design power stations**

On our newer larger plants with an output of greater than 500 MW, where the condensers are larger and the pump flow greater, the condensate extraction pumps are vertical multistage with the pump element mounted in a suction can which is connected directly to the hot-well of the condensers. In this way the first stage impeller is way down at the bottom of the suction can. The length of the can is determined by the NPSH required by the first stage impeller of the pump. The vertical CEP's run at two pole speed (1500 rpm).

All the power stations, whose outputs are greater than 500 MW per unit, have main turbine bypass systems. In this case the design point "A" of the pumps are designed and selected/sized to accommodate the full low pressure bypass flow during a main turbine trip operation. The total flow of the CEP will include the main forward condensate flow as well as the spray water requirement to the LP turbine bypass control valve station.

The turbine MCR or duty point "C" will then be obtained by throttling the main condensate control valve, see fig. 1.

The condensate flow of the CEP is also controlled during part load operation by throttling the main condensate control valve further on the pump curve (artificially increasing the system resistance). In the case of a LP turbine bypass operating condition, the main condensate control valve will open fully and the pump will run at the design point "A" of the pump, see fig. 1. The NPSH required and NPSH available needs to be satisfied at this design point and the motor power requirement also needs to be considered for this design point.



**Figure 1. Condensate extraction pump – fixed speed pump curve**

#### *CEP configuration*

Based on an economic evaluation and using all factors as listed in the section *Condensate extraction pump configuration*, it was concluded that a  $2 \times 100\%$  duty CEP configuration would be the optimal CEP configuration for the expected 50 year life span of a power station.

#### *Vertically arranged vs. horizontally arranged CEP's*

The two new supercritical power stations Medupi and Kusile will be utilizing an air cooled condenser (ACC) for condensing the steam from the main turbine. In this case the CEP's will not take suction from the hot-well of the condenser which is normally under vacuum for a wet cooled system, having low NPSH available. The air cooled condenser condensate tank (ACCCT) is installed at 15 m level above grade and would therefore be able to supply sufficient NPSH available to the CEP's to consider a horizontally arranged CEP.

With this pump selection and operating mode the best efficiency point (BEP) of the pump is at the design point "A" and not the turbine MCR duty point "C".

To summarize: The CEP will run at a reduced efficiency as well as a throttled operating condition during turbine MCR operating condition. This condition results in unnecessary auxiliary power usage or "wasted" energy consumption over the life span of the power station.

#### **Condensate extraction pumps for the two new supercritical power stations**

During the feasibility studies and the technical clarifications meetings for the equipment to be supplied for the two new supercritical power stations, the following options for the CEP's were considered:

- CEP configuration,
- vertically arranged vs. horizontally arranged CEP's, and
- variable speed vs. fixed speed electrical motor driven CEP's.

Both vertically arranged and horizontally arranged CEP configurations were considered.

The following table with arrow coding was used to help determine which CEP configuration would be optimal for the Medupi and Kusile power CEP's.

### Conclusions

From tab. 1, considering all technical aspects as well as NPSH requirements for the CEP's the horizontal CEP arrangement was selected for the two new supercritical power stations, Medupi and Kusile.

#### *Variable speed vs. fixed speed electrical motor driven CEP's*

As explained in the section *Condensate extraction pumps installations in newer larger design power stations*, the CEP's run at a reduced efficiency as well as a throttled operating condition during turbine MCR operation conditions. With the aid of fig. 1, a variable speed CEP option was investigated and considered.

The reduced efficiency and throttled operating conditions results in unnecessary auxiliary power usage or "wasted" energy consumption over the life span of the power station.

It was therefore important to consider a variable speed CEP for the two new supercritical power stations, Medupi and Kusile.

By utilizing a variable speed CEP on "A" CEP the following power savings are achieved at duty point "C" or turbine MCR operating point, see fig. 2 and tab 2.

From tab. 2 one can clearly see that there is a significant saving in the power absorbed by the CEP at turbine MCR operating conditions, when the fixed speed unit is compared with the variable speed unit. The variable speed option will also give a power saving at loads below turbine MCR conditions, *i. e.* part load (the flow is directly proportional to the speed of the pump). The motors selected for the fixed speed and variable speed CEP's are the same (they will be interchangeable). The only difference is the actual variable speed control coupled to "A" CEP motor.

**Table 1. Technical considerations used to evaluate the vertically and horizontally arranged CEP**

	Vertical	Horizontal
Pump design		
Installation weights and maintenance		
Pump duty points		
Pump materials		
Electric motors		
Spares holding		
Positioning of CEP's		
Past Eskom P/S CEP's		
References		
Local manufacture		

indicating a lower rating;    indicating higher rating

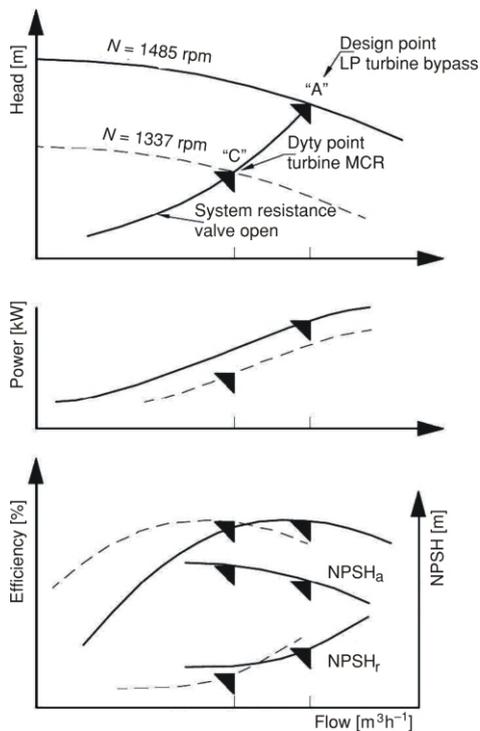


Figure 2. Condensate extraction pump – variable speed pump curve

During normal operation at turbine MCR operating conditions, the “A” variable speed CEP will run at a reduced speed of  $N = 1377$  rpm, with the main condensate control valve in the fully open position and the actual pump discharge pressure lower (no throttling across valve). As soon as the unit is operated in a main turbine bypass operating condition the pump will increase in speed to a speed of  $N = 1485$  rpm with the main condensate valve still fully open and operating at the required LP turbine bypass or design point “A” condition. The load of the unit will also be controlled by the speed of the pump.

The power saving using a variable speed CEP justified the capital layout in using a VSD on one of the CEP’s.

In the case of a trip on “A” CEP the fixed speed pump will start and the main condensate control valve will then control the required condensate delivered by the fixed speed CEP by throttling the pump to the required flow on the fixed speed pump curve.

Table 2. CEP power absorbed at turbine MCR operating condition for the fixed speed and variable speed pumps

Power absorbed at turbine MCR operating condition	
Fixed speed CEP	1410.05 kW
Variable speed CEP	1082.80 kW
Saving in kW and %	327.25 kW and 30% saving

- 2 50% duty standby electrically driven boiler feed pumps complete with geared variable speed fluid drive couplings (Eskom standard on wet cooled condenser power stations), and
- 3 50% duty, variable speed electrically driven boiler feed pumps, two in parallel operation and one 50% on standby (Eskom standard on dry-cooled power stations).

When comparing the two BFP configurations the following was considered:

- initial capital costs,
- piping and instrumentation, including valves,

## BOILER FEED PUMPS

### Boiler feed pump configuration

The following boiler feed pump (BFP) configurations were considered:

- 1 100% duty, steam turbine driven boiler feed pump, and

- electrical cabling and systems,
- space required for installation,
- redundancy,
- spares holding, and
- effect of BFP turbine exhaust on cycle efficiency should a 100% duty, steam turbine driven boiler feed pump be installed on a dry cooled station.

As determined by an economic evaluation using all factors as stated above, it was concluded that a  $3 \times 50\%$  duty variable speed electrically driven BFP configuration would be the optimal configuration for the expected 50 year life span of the power station.

#### *Boiler feed pump variable speed drives*

The BFPs for the  $3 \times 50\%$  duty electrically driven variable speed pumps will consist of the following:

- a booster pump,
- a main pump, and
- a variable speed drive situated between the booster and the main pumps.

*Note:* The boiler feed pumps and drives considered will be sized and selected to satisfy the design point of the power station which is HP bypass operation or design point “A”.

#### **Pump variable speed drive selection**

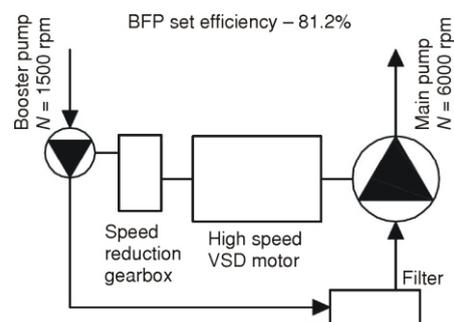
Four alternative variable speed drives were considered, namely:

- high speed VSD motor with speed reduction gearbox,
- low speed VSD motor with speed increase gearbox,
- voith Vorecon variable speed planetary gear fluid drive coupling, and
- voith variable speed fluid drive coupling.

#### *Boiler feed pump drive option 1*

With this drive option a high speed variable speed electric motor is directly connected to the main pump. A speed reduction gearbox links the other side of the high speed motor shaft to the booster pump, see fig. 3.

This drive option will have the highest BFP set efficiency of 81.2% (pumps, motor and gearbox combined) with the lowest power consumption (12.14 MW at turbine MCR operating condition for one BFP set). Another advantage would be that the BFP set will also run at very high efficiency and low power consumption at part load conditions.

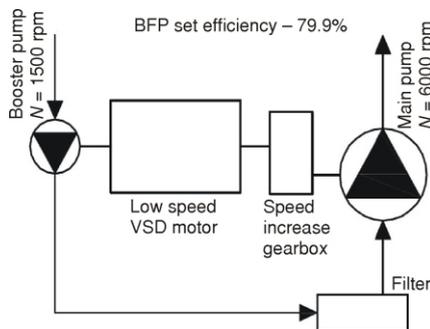


**Figure 3. High speed VSD electrically driven motor with a speed reduction gearbox**

The biggest disadvantage would be the initial capital cost of the variable speed drive and high speed electric motor.

Eskom has experience of this BFP layout and drive option at our Matimba, Kendal, and Majuba power stations. It is proven technology which contributes to high availability and reliability of the complete BFP train.

#### Boiler feed pump drive option 2

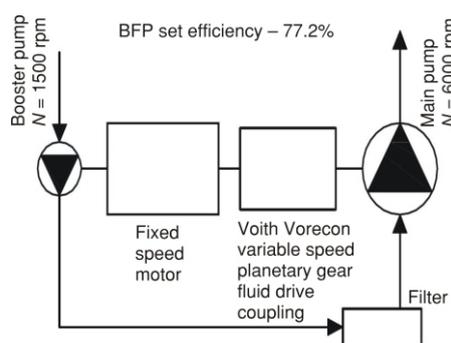


**Figure 4. Low speed VSD electrically driven motor with a speed increase gearbox**

With this drive option a low speed variable speed electric motor is directly connected to the booster pump. A speed increase gearbox links the other side of the high speed motor shaft to the booster pump, see fig. 4.

This drive option will also have a high BFP set efficiency of 79.9% (pumps, motor and gearbox combined), with low power consumption (12.34 MW at turbine MCR operating condition for one BFP set). The BFP set efficiency will not be as high as that for option 1 due to the speed increase gearbox losses (driving the main pump ~11.2 MW). An advantage would be that the BFP set will also run at very high efficiency and low power consumption at part load conditions.

As the capital cost of a low speed variable speed electric motor is lower than that for a high speed variable speed electric motor, option 2 will be more cost effective than option 1 but is still high when compared to drive options 3 or 4.



**Figure 5. Fixed speed electric motor with Voith Vorecon variable speed planetary geared fluid drive coupling**

Eskom has no experience with this drive option and Eskom would require access to reference plant and detailed technical information for this drive option before it would be seriously considered.

#### Boiler feed pump drive option 3

This BFP drive option utilizes an advanced fluid drive coupling – Voith Vorecon variable speed planetary gear fluid drive coupling, see fig. 5.

In this option the booster pump will be connected directly to an 19 MW – 4 pole double shaft extension, 6.6 kV induction motor.

The Voith Vorecon variable speed planetary gear fluid drive coupling will connect the other end of the motor shaft to the main pump.

The main pump flow will be regulated by increasing or decreasing the speed of the Voith Vorecon variable speed planetary gear fluid drive coupling.

This drive option will have a lower BFP set efficiency of 77.2% when compared to options 1 or 2. It will also absorb more power (12.76 MW, at turbine MCR operating condition for one BFP set), than options 1 or 2. This option does however have advantages when compared to option 4 where at part load conditions the efficiency of the BFP set will be lower than options 1 or 2 but higher than option 4 [2].

This BFP drive option will have a substantially lower capital cost than options 1 or 2, but still greater than option 4.

Eskom has no experience with the Voith Vorecon variable speed planetary gear fluid drive coupling. A reference list was made available by Voith listing the installations where Voith Vorecon variable speed planetary geared fluid drive couplings are in use. The reference list includes: boiler feed pumps, fans, compressors, coal mills, and ID fans [3].

The two highest power rating Vorecon's built and supplied for a BFP application are:

- 9.9 MW, 3 units installed 2004 (Flowsolve, Weston, USA), and
- 8.5 MW, 2 units installed 1989 (Mannheim, Grosskraftwerk, Germany).

The two highest power rating Vorecon built and supplied to industry are:

- 28 MW, 1 unit installed 2005, compressor drive test stand (Shenyang Blower Works, Shenyang, China), and
- 14.8 MW, 1 unit installed 2004, Compressor drive (BHEL, Lekhwaier Gas Iwecton, Oman).

The 50% BFP unit considered for Medupi and Kusile will absorb 12.34 MW at turbine MCR and 17.2 MW at run-out duty point.

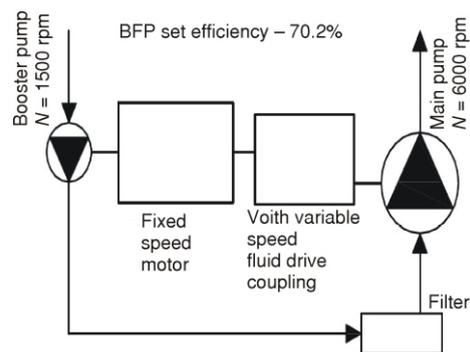
#### Boiler feed pump drive option 4

This BFP drive option utilizes a Voith variable speed fluid drive coupling.

In this option the booster pump will be connected directly to an 19 MW – 4 pole double shaft extension, 6.6 kV induction motor. The Voith variable speed fluid drive coupling will connect the other end of the motor shaft to the main pump, see fig. 6.

The main pump speed will be regulated by increasing or decreasing the speed of the Voith variable speed fluid drive coupling.

This drive option will have the lowest BFP set efficiency of 70.2% compared to options 1, 2, or 3. It will also absorb more power



**Figure 6. Fixed speed electric motor with Voith variable speed fluid drive coupling**

(14.05 MW, at turbine MCR operating condition for one BFP set), than options 1, 2, or 3. This option has a further disadvantage when compared to option 3 where at part load conditions the efficiency of the BFP set will be reduced due to the high slip losses in the fluid drive coupling.

This BFP drive option will have the lowest capital cost when compared to options 1, 2, or 3. Eskom has experience with the Voith variable speed fluid drive couplings at the Matla, Duvha, Lethabo, and Tutuka power stations. The BFP's which are equipped with the Voith variable speed fluid drive couplings at these power stations are only used for unit start up and shut down or used as standby BFP's in the case of unavailability of the 100% duty, steam turbine driven boiler feed pump.

### Summary of the BFP drives

Table 3 summarizes the BFP set efficiencies, power consumption using two 50% BFP in parallel at turbine MCR operating condition and initial capital costs.

**Table 3. Boiler feed pump drive option, efficiency, power absorbed, and capital costs**

BFP drive option	BFP set efficiency [%]	Power consumption [kW]	Capital cost [%]
High speed VSD electric motor with speed reduction gearbox	81.2	24274.8	203
Low speed VSD electric motor with speed increase gearbox	79.9	24685.2	161
Fixed speed motor with Voith Vorecon variable speed planetary geared fluid drive coupling	77.2	25520.84	133
Fixed speed motor with Voith variable speed fluid drive coupling	70.2	28103.1	100

### Economic evaluation of the boiler feed pump drive options

Although all four BFP drives were technically acceptable with emphasis on BFP set efficiency and power absorbed, the final decision is dependant on the economic evaluation results.

The new Eskom generation economic evaluation model was used to calculate the levelised costs of the four drive options over the expected 50 years life span of the power station.

The economic evaluation included:

- capital costs,
- absorbed power,
- operating philosophy of power station,
- availability and reliability of plant,

- auxiliary power costs, and
- maintenance costs.

The results from the economic evaluation model yielded the following order of preference:

- (1) fixed speed motor with Voith Vorecon variable speed planetary gear fluid drive coupling,
- (2) low speed VSD motor with speed increase gearbox,
- (3) fixed speed motor with Voith variable speed fluid drive coupling, and
- (4) high speed VSD motor with speed reduction gearbox.

### Conclusions and recommendation on the BFP drives

Based on the economic evaluation results Eskom investigated the fixed speed motor with Voith Vorecon variable speed planetary gear fluid drive coupling further by visiting Mannheim power station in Germany and SES Meliti power station in Greece both of whom utilize Vorecon BFP drives. The visit was specifically aimed at gaining operational and maintenance experience from the two users [4]. The two Vorecon's installed in Mannheim Power Station have been in service for more than 100 000 operating hours since installation.

Based on the high reliability and availability of the Voith Vorecon's installed as BFP drives at Mannheim and SES Meliti Power Stations, it can be concluded that this BFP drive option is viable and proven. The selection of the Voith Vorecon BFP drive is therefore the preferred and accepted boiler feed pump drive for Medupi and Kusile power station and should also be considered for future power stations.

It was therefore concluded and recommended that the Medupi and Kusile power station boiler feed pump configuration remains as per the original specification; *i. e.* 3 50% duty electric motor driven boiler feed pump sets in conjunction with a Voith Vorecon hydraulic drive coupling.

The final contract signed with Alstom for the 3 50% boiler feed pump sets per unit for the six units at the Medupi power station consists of the following equipment:

- Sulzer booster pumps – HZB 303-720,
- Sulzer main pumps – HPT 350-370-6S/29, and
- ABB electric motor – squirrel cage induction motor DQWGH 1000/4-274 and Voith Vorecon – RW16-145 F 9.

### ACKNOWLEDGEMENTS

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### Nomenclature

- $H$  – head, [m]
- $N$  – rotational speed, [rpm]
- $NPSH$  – net positive suction head, [m]

$NPSH_a$  – net positive suction head available, [m]  
 $NPSH_r$  – net positive suction head required, [m]  
 $P$  – power, [kW]  
 $Q$  – flow, [m<sup>3</sup>/h]  
 $\eta$  – efficiency, [%]

#### Accronimes

ACC – air cooled condenser  
ACCCT – air cooled condenser condensate tank  
BEP – best efficiency point  
BFP – boiler feed pump  
CEP – condensate extraction pump  
EE – economic evaluation  
HP – high pressure  
ID – induced draught  
LP – low pressure  
MCR – maximum continuous rating  
P/S – power station  
ST – steam turbine  
TMCR – turbine maximum continuous rating  
VSD – variable speed drive

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## Апстракт

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## **Избор оптималне конфигурације и начина рада пумпи за испумпавање кондензата и пумпи за снабдевање напојном водом за нове Еском термоелектране са наткритичним параметрима**

Компанија Еском је отпочела капитални инвестициони програм да би задовољила растућу потребу за електричном енергијом у економији Јужноафричке Републике која се интензивно развија задњих година. Будући развој подразумева производњу електричне енергије уз коришћење различитих технологија, као што су: сагоревање фосилних горива, нуклеарне енергије, модуларни реактори са флуидизованим слојем, гасних циклуса, енергије водених токова, комбинована производња топлотне и електричне енергије, енергија из ветра и сунчева енергија.

Прве две, од планираног већег броја нових термоелектрана са наткритичним параметрима, Медупи (6 блокова, сваки по 794 MW) и Кусиле (6 блокова, сваки по 798 MW) су у поступку пројектовања и изградње.

Пумпе за испумпавање кондензата и снабдевање напојном водом су међу највећим потрошачима електричне енергије у термоелектранама, тако да њихов избор и избор одговарајућег начина рада представља примарни задатак у процесу пројектовања ових система.

У раду су описани начини коначног избора пумпи за испумпавање кондензата на две новоизграђене термоелектране са наткритичним параметрима у Јужноафричкој Републици. Разматрана је опција вертикалног постављања са ваздушно хлађеним кондензатором у односу на хоризонтално постављање пумпи за испумпавање кондензата. Свака од пумпи за испумпавање кондензата је димензионисана за 100%-тно оптерећење у бајпасном моду рада. У раду је објашњено зашто је изабрана конфигурација са две пумпе са 100%-тним оптерећењем од којих је једна са електромотором са променљивом брзином и друга са електромотором са непроменљивом брзином обртања.

Да би се обезбедила висока поузданост снабдевања напојном водом, три пумпе са 50% оптерећења по блоку ће бити постављене на две нове термоелектране са наткритичним параметрима.

У раду су, такође, описана четири различита радна режима пумпи за снабдевање водом које су биле расположиве приликом избора.

Детаљи сваког режима рада пумпи су описани и дискутовани. Коначна одлука приликом избора пумпи напојне воде је заснована на економском моделу процене који је узео у разматрање три различита мода рада, почетну цену изградње, потрошњу електричне енергије у раду и захтевану ефикасност рада напојних пумпи у предвиђеном педесетогодишњем животном веку рада термоелектрана.

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Еском компанија је електропривреда Јужноафричке Републике. Еском је пета компанија у светским размерама у односу на производњу електричне енергије, покрива 95% потреба Јужноафричке Републике и 45% електричне енергије која се произведе на Афричком континенту.

Кључне речи: *Еском, најкритични параметри рада термоелектрана које сагоревају фосилна горива, пумпе за испумпавање кондензата, најбоље пумпе, електропомп са променљивим бројем обртаја*

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