The Novel Design of Feed-water Control System for Thermal Power Plant Using Super-critical Start-up Motor-Boiler Feed-water Pump

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***Abstract*— In normal condition of thermal power plant, the boiler feed-water pump (BFP) speed modulates to control economizer feed-water (FW) flow, and/or the regulation valve is used for start-up and low load. However, super-critical motor-BFP at its minimum speed can not sufficiently modulate to control economizer FW flow during low pressure boiler start-up. Moreover, the requirement of high drop pressure can not be achieved with one control valve given the wide flow control range required. Therefore, the study conducts the experiment and evaluation for a novel design with additional letdown control valves downstream pump in series with regulation valve to control feed-water during unit start-up and low load for the configuration of super-critical Motor-BFP. The results show that the ramp rates of temperature and pressure per minutes are equivalent and within permission of ASME codes in comparison with the configuration of sub-critical Motor-BFP with one control valve during start-up time tests. From the results of the study, it is advisable that Vietnam can apply this viable design for the new thermal power units in order to proof against the increase of periodic start-ups or partial shutdowns caused by the problems related to variable renewable electricity and potential grid stability in the near future.**

***Index Terms*— Feed-water, thermal power plant, start-up, low load, control valve, boiler feed-water pump.**

I. INTRODUCTION

In 2019, Vietnam grid power demand reached nearly 38,000 megawatts at peak hours and the fluctuated about 10,000 megawatts at off-peak hours, and the renewable energy sources as wind and solar photovoltaic also passed 9% of total installed capacity. In Vietnam scenario, it is predicted to face with problems related to variable renewable electricity and potential grid stability. The fossil-fired power plants shall increase the periodic start-ups or partial shutdowns caused by balance of the electricity system [1-3]. Therefore, the optimization studies for faster start-ups of thermal power units in order to decrease fuel consumption and emission but still keeping the allowable stress because of higher ramp rates are necessary.

Currently, the models and simulations for unit start-up dynamic process including thermo-hydraulic analysis, control structures, stress calculation, and using software code as Apros which have been studied by many researchers [4-6]. In addition, the regulating characteristics analysis and experimental performance curve of boiler feed-water pump under different operations have been presented in [7-8]. However, the experiment and evaluation for feed-water control system during unit start-up and low load is rare.

In normal condition of thermal power plant, the boiler feed-water pump (BFP) speed modulates to control the economizer's feed-water (FW) flow, and/or the regulation valve is used for start-up and low load. However, 50% capacity super-critical Motor-BFP at its minimum speed is not only sufficiently modulated to control the economizer's FW flow during low pressure boiler start-up, but also the high drop pressure requirement cannot be achieved with one control valve given the wide flow control range required. Consequently, this study conducts the experiment and investigation for a novel design with additional letdown control valves downstream pump in series with regulation valve that is established to control feed-water during unit start-up and low load for the configuration of super-critical Motor-BFP. The result shows that the ramp rates of temperature and pressure are 0.3~1.4 ºC/min & 0.02~0.08MPa/min within permission of ASME codes during start-up time test.

II. METHOS AND DATA

A. Object

The Boiler feed-water system provides two (2) flow paths from the deaerator storage tank. The bigger one moves feed-water to the economizer inlet, passing high-pressure regenerative heaters to raise its temperature. And the second provides the flow with the necessary pressure for spray water to the superheat, reheat, and high-pressure turbine bypass attemperators. Boiler FW flow is controlled by pump speed when boiler load is above 30%. During the boiler start-up stage, the boiler FW flow is controlled by the start-up FW control valve.

The objects of this study include two (2) following super-critical large-scale (+600MW) power generation units in Vietnam:

- Vinh Tan 4 Thermal Power Plant (VT4) located at Tuy Phong District, Binh Thuan Province with the configuration of one 30% capacity constant speed electric motor driven pump provided for supplying feed water during unit start up only, and two 50% capacity steam turbine driven main boiler feed pumps (with shaft driven suction booster pumps) provided to supply FW during normal operation [9].

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- Duyen Hai 3 Extension Thermal Power Plant (DH3E) located at Duyen Hai District, Tra Vinh Province with three 50% capacity, motor driven, variable speed main boiler feed pump and constant speed boiler feed booster pump assemblies [10].

B. *Feed-water control*

1) Feed-water control options: there are two feed-water control options as follows:

a) Method 1:

- BFP speed modulates to control economizer FW flow for all operating scenarios;
- FW regulation valve modulates to control SH Spray back-pressure (differential pressure dP control) for start-up and low load.

b) Method 2:

- Start-up and low load (main FW block valve closed): FW regulation valve modulates to control economizer FW flow and BFP speed modulates to control FW regulation valve dP;
- Normal operation (main FW block valve open): BFP speed modulates to control economizer FW flow and FW regulation valve closed.

A Feed Water Regulation Control Valve (FRCV) is required for *(i)* To control FW flow to economizer up to 35% Boiler Maximum Capacity Rate (BMCR) included margin since. At ~30% the SH attemperator sprays will be fed from economizer outlet; *(ii)* To maintain dP between economizer and SH attemperator sprays below 35% BMCR.

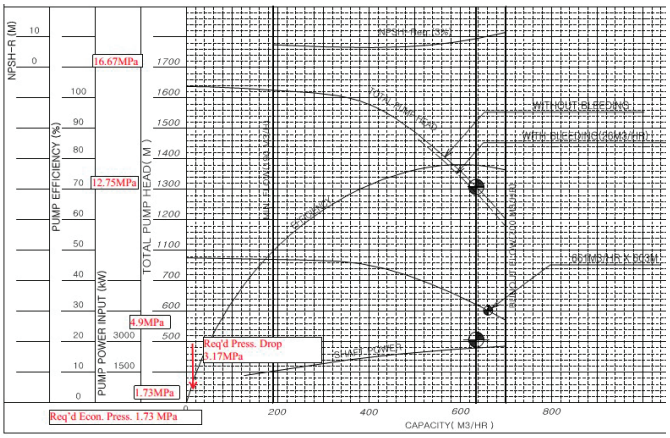

Fig. 1. Performance curve of Sub-critical Mortor-BFP

Fig. 2 presents the performance curve for combined pump-set of sub-critical Motor-BFP:

- Drum pressure requirement (1.73 MPa)
- Minimum working pressure of boiler feed-water pump (4.9MPa)
- Required pressure drop 3.17MPa is easily achieved with one control valve given wide flow control range required.

As Fig.3 shows, the performance curve for combined pump-set of super-critical Motor-BFP consists of:

- Economized pressure requirement (1.73 MPa)
- Minimum speed of BFP 2500 rpm (9.17 MPa)
- Required pressure drop 8.08 MPa cannot be achieved with one control valve given the wide flow control range required.

c) Selected Feed-water Control Option: The only viable method for DH3E

BFP at its minimum speed can not sufficiently modulate to control economizer FW flow during low pressure boiler start-up. Therefore, Letdown Control Valves (LCV) is necessity to reduce BFP pressure prior to economizer & water collecting tank (WCT) during:

- Cold Clean-up
- Low Pressure Boiler Start-up, < 7,600 kPa(g) (≤ 11% BMCR)
- Function of BFP unit turndown capabilities & super-critical power coal-fired unit design pressure.

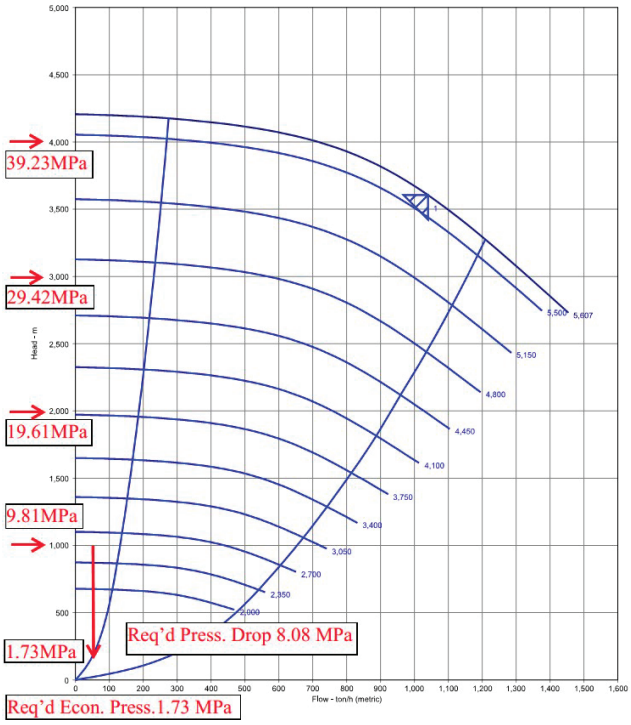

Fig. 2. Performance curve of BFP for Super-critical Motor-BFP

d) Feed-water control summary: DH3E FW control summary is shown on Fig. 3,4,5,6&7.

Cold clean-up & low pressure start-up (Main FW block valve closed)

- FRCV modulates to control economizer FW Flow
- LCV modulates to control FRCV differential pressure (dP)
- BFP speed forced to minimum

High pressure start-up & low load (Main FW block valve closed)

- FRCV modulates to control economizer FW Flow

- BFP speed modulates to control FRCV dP
- LCV - CLOSED

Normal operation (Main FW block valve open)

- BFP speed modulates to control economizer FW flow
- FRCV – CLOSED

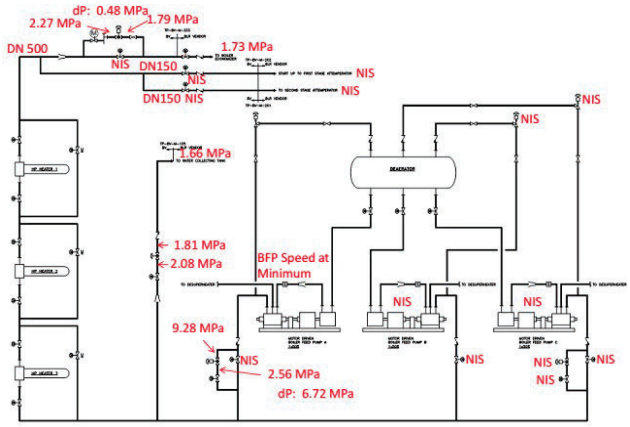

Fig. 3. Feed-water control for low pressure boiler start-up <11% BMCR

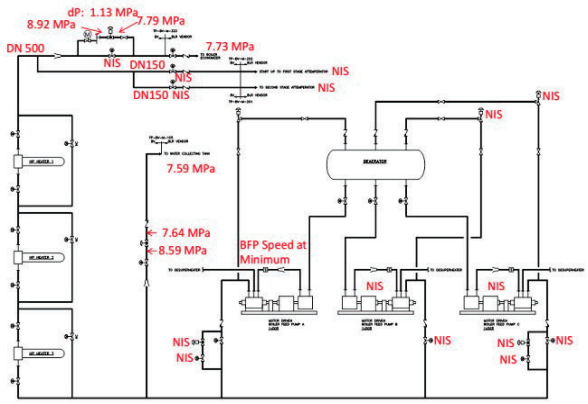

Fig. 4. Feed-water control for low pressure boiler start-up <15% BMCR

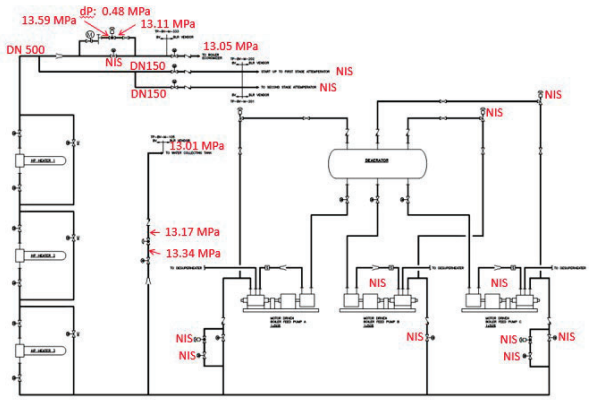

Fig. 5. Feed-water control for high pressure boiler start-up <15% BMCR

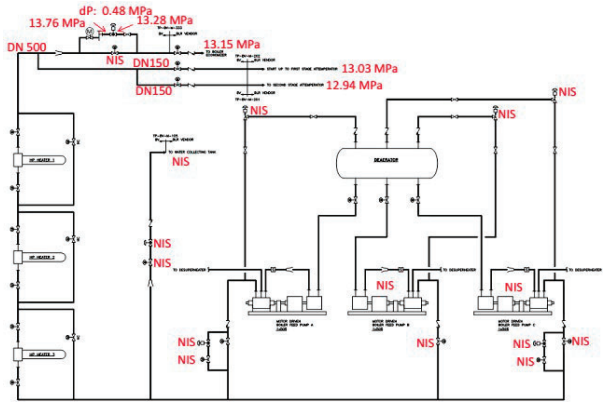

Fig. 6. Feed-water control <35% BMCR

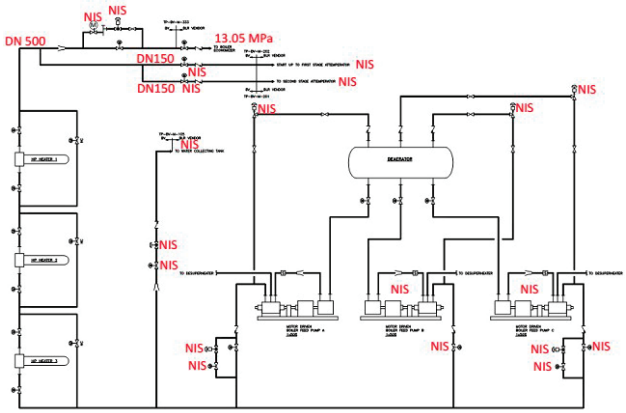

Fig. 7. Feed-water control >35% BMCR

2) Control description and logic diagram:

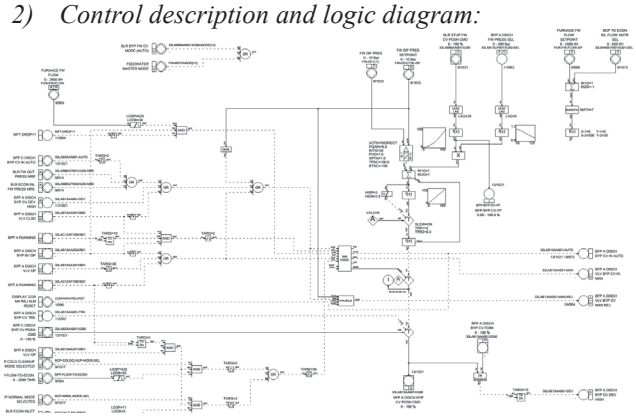

Fig. 8. Logic diagram of letdown control valve

During Cold Cleanup and Boiler low pressure startup conditions, the available BFP discharge pressure is not allow proper FW flow control at the conditions. The BFP LCV reduces the pressure to satisfy the manufacturer's requirements. BFP LCV controls the differential pressure across the Boiler FRCV (33LAB80AA001) when the BFP is running, the LCV (33LAB13AA201) is closed and the BFP discharge bypass valve 33LAB13AA203 is open. When 33LAB13AA203 is not open, OR, BFP not running, OR, 33LAB13AA201 is fully open, it shall remain closed. When cold clean-up mode selected, BFP running and economizer inlet flow < 525 t/h, OR, normal mode selected and BFP

running (33LAC12AP100) and economizer inlet pressure (33LAB00CP002/33LAB80CP003/33LAB80CP004) <76barg, automatically commands 33LAB13AA203 and 33LAB13AA001 open. When 33LAB13AA201 is not closed, it will reject to manual. When block valve 33LAB13AA203 goes fully open and 33LAB13AA201 goes fully closed, it shall be in auto.

Fig. 9. Cold start-up of VT4

Fig. 10. Warm start-up of DH3E

III. Results and Discussion

A. Start-up of VT4

The ramp rates of throttle pressure in green color line No. 8 line is 0.02 MPa/min and super-heater outlet temperature in No. 10 line is 1.2 ºC/min fr om lighting off to pulverized start, and temperature 0.55 ºC/min until turbine roll, from synchronizing to 35% BMCR the rate is 0.62 ºC/min and 0.016 MPa/min. When >35% BMCR is 0.01 MPa/min & 0.5 ºC/min and high load is 0.013 MPa/min as shown on Fig. 9.

B. Start-up of DH3E

The throttle pressure 0.02 MPa/min and super-heater outlet temperature 0.3 ºC/min ramp rates is from lighting off to pulverized start, and then the ramp rates are 1.4 ºC/min and 0.08 MPa/min until turbine roll, from synchronizing to 35% BMCR is 0.8 ºC/min of ramp rate. When >35% BMCR is 0.13 MPa/min and 0.45 ºC/min, and high load is 0.12 MPa/min ramp rate as indicated on Fig.10.

C. Comparition

The fluctuations of the temperature and pressure between VT4 and DH3E is equivalent and comply with the permissible deviation of variables and operating parameter deviations of ASME PTC 4 & 6 during start-up time test.

TABLE I. The Ramp Rate of Pressure and Temperature During Start-up Time Test

Start-up	The Ramp Rate of Pressure and Temperatures		Remark
	VT4 Cold	***DH3E Warm***	
From light off to pulv. Start	0.02MPa/min	0.02M Pa/min	The fluctuation is equaled and meet ASME PTC 4&6 codes during time test.
	1.2 ºC/min	0.3 ºC/min	
Turbine roll	0.55 ºC/min	0.08MPa/min	
		1.4 ºC/min	
From sync. to 35% BMCR	0.016MPa/min	0.8 ºC/min	
	0.62 ºC/min		
>35% BMCR	0.01MPa/min	0.13MPa/min	
	0.5 ºC/min	0.45 ºC/min	
High load	0.013MPa/min	0.12MPa/min	

The results show that the ramp rates of temperature and pressure are equivalent in comparison with configuration of 30% capacity sub-critical Motor-BFP + one control valve and according to permit of ASME codes during start-up time test

IV. Conclusions

The experiment and evaluation for the ramp rates of temperature and pressure per minutes between the feed-water control configuration of sub-critical Motor-BFP and super-critical Motor-BFP during unit start-up and low load were carried out in this study. The results showed that the ramp rate of this novel design with additional letdown control valves downstream pump in series with regulation valve was reliable within acceptation of ASME codes during start-up time test.

Subsequently, it is suggested that Vietnam can apply this viable design for the new thermal power units in order to reduce start-up costs as well as environmental impacts.

Acknowledgment

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