Study on the VFD (Variable Frequency Drive) for RCP (Reactor Coolant Pump) Motors of APR1400.

JungHa Park, Robert.M.Field, Tae-Ryong Kim

Department of NPP Engineering. KEPCO International Nuclear Graduate School

Objective

Variable Frequency Drive (VFD) Units to RCP Application

To examine benefits and design considerations of VFD units and to make a recommendation regarding VFD applicability to the RCP motors on the APR1400 design

Fig. 1 : VFD (Variable Frequency Drive) Unit

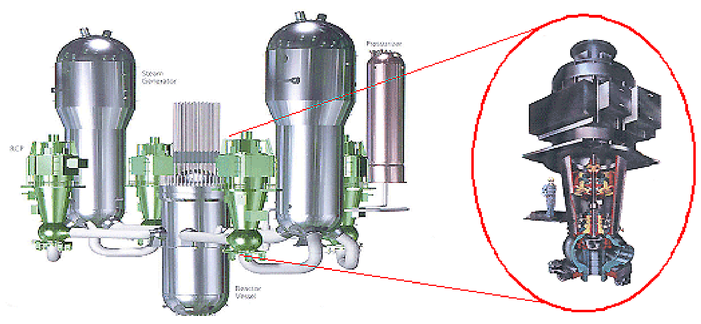

Fig. 2 : RCP (Reactor Coolant Pump) for APR 1400

Electrical Analysis and Results

RCP motor start is a challenge due to the massive RCP flywheel

- **Starting Current** (ETAP modeling and analysis)

Soft starting benefits:

(1) No process disturbance due to voltage drops, no trips of other electrical devices connected to the same bus

(2) No excessive thermal or mechanical stress on the motor, pump impeller shaft, or coupling, resulting in a longer lifetime

(3) Controlled and smooth start-up in driven system process parameters

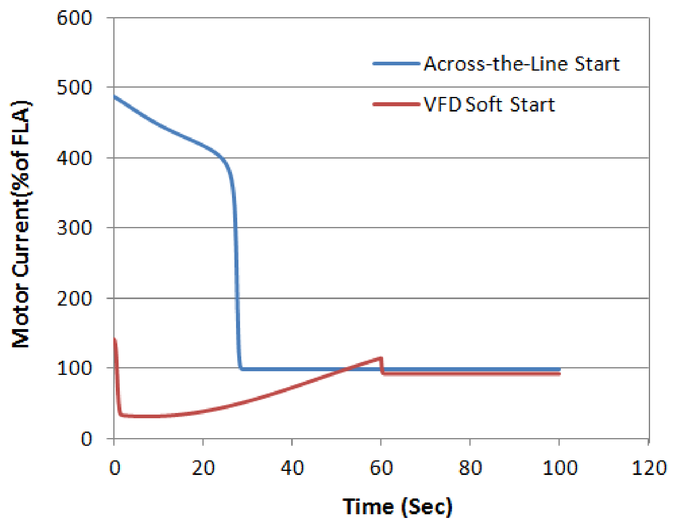

Fig. 3: Comparison of Starting Current
[FLA: Full Load Ampere]

-Short Circuit Analysis

VFD units make it possible to use more economical equipment with lower ratings, such as circuit breaker, cables, and so on. From Table 1, the limiting short circuit current is about 2[kA], so VFDs can provide margin when selecting the Circuit Breaker. VFD can provide margin for rated short circuit current. According to Table 1, we can select the lower rating for short circuit breaker, so it can make cost saving possible.

Electrical Analysis and Results

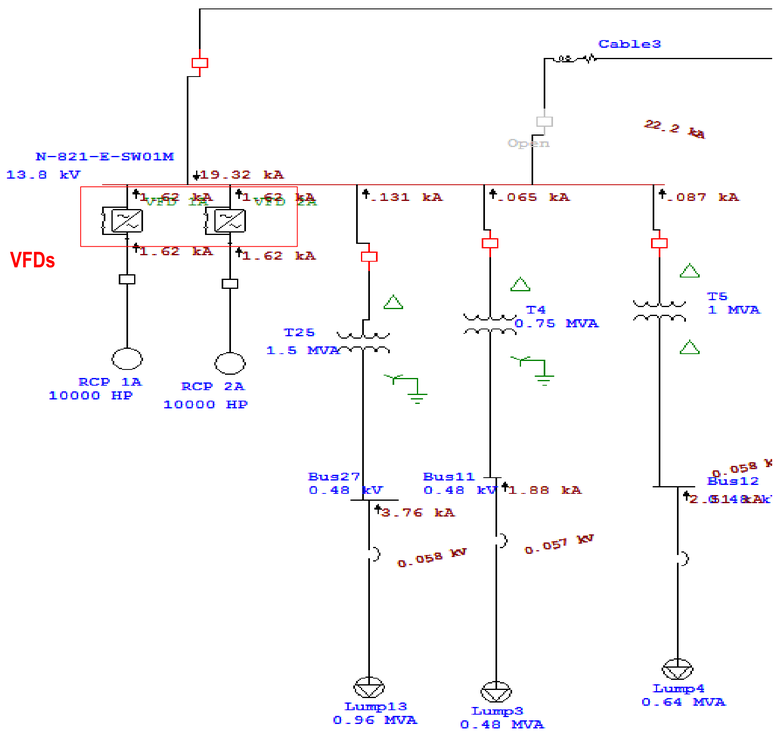

Fig. 4 : Single Line Diagram for Short Circuit Analysis

MODE	Bypass[kA]	VFD[kA]
Short Circuit Current	22.2	19.6
15% margin	3.3	2.8
Total Current	25.5	22.4
Selection of Circuit Breaker	**31.5**	**25**

Table 1 : Selecting Circuit Breaker Bypass and VFD Mode during 1/2 Cycle

FMEA (Failure Mode Effects Analysis)

Increase & Decrease in RCP Speed

- When using VFD units, the increase or decrease in flow due to malfunctions will be gradual due to the high mass moment of inertia of the RCP flywheel.

Trip of RCP

- A controller failure which results in the trip of one or more RCPs would be covered by the existing licensing design basis. Not further evaluations would be required.

Cost Benefit Analysis

RCP Motor Size Reduction 13,500 →10,000 HP

Limiting RCP motor duty (13,500 HP) is under cold, startup conditions. Using VFD units during heat-up, the RCP allowable speed can be based on reactor coolant temperature to remain within the reduced motor rating (10,000 HP). Plant startup and shutdown occurs only once every 18 months, this amount of energy cost savings would be very small .

Simulation for increasing Flywheel Mass

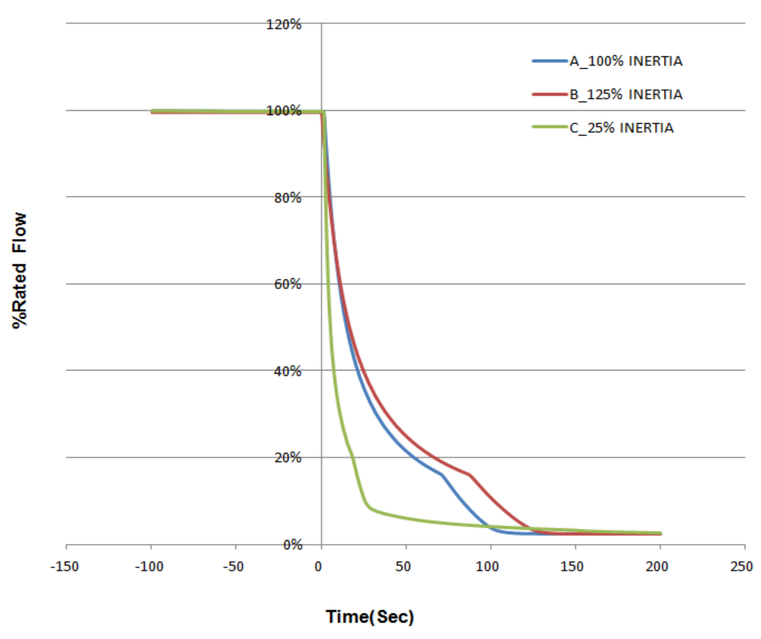

Fig. 5: Pump Flow Coast-Down

Licensing Impact

1) Review of Westinghouse AP1000 Design

The AP1000 design employs VFD units.
Two RCS loops shall be OPERABLE with four Reactor Coolant Pumps (RCSs) in operation with variable speed control bypassed. (MODE 1, 2 and MODE 3, 4, 5 whenever the reactor trip breakers are closed.)

2) Preparation of APR1400 SSAR revision

Section	Before	After
5.4.1.2 Description	<None>	Each pump motor is driven by a variable speed drive, which is used for pump startup and operation when the reactor trip breakers are open. When the reactor trip breaker is closed, the variable frequency drives are bypassed and the pumps run at constant speed.
16.3.4.4 RCS Loops (Mode 1 and 2)	Two RCS loops shall be operable and in operation	Two RCS loops shall be operable and in operation with variable speed control bypassed.

Table 2 : Preparation of APR1400 SSAR revision with VFD

Conclusion

Classification	Model	APR1400 (General motor)	AP1000 (Canned motor)
Design	RCP Motor Size	Big - Cold water	Small - Hot
	Mechanical seal	Yes	No(Canned Motor)
	Proven Design	Equivalent Palo Verde	No
	Anti-reverse Rotation Mechanism	Required	Not required
	Short circuit duty	Standard	Minor Reduction
Operation	RCS Flow/MWt	Very Good (484kgpm/4000MW)	Poor (316kgpm/3420MW)
	Coast down following trip	Excellent	Poor
	Parasitic Power (Flywheel)	~0 [MWe]	~2.5 [MWe](4x625kW)
	Soft Start (VFD)	No	Yes
	Standby RCP power Consumption	High	Low
Nuclear Safety	Loss-of-thermal Barriers-(Small Break) LOCA	Yes	No
	Shutdown Seal	Applicable	Not Required
Maintenance	60 year Maintenance Free	No	Yes
	Motor Removal	Easy	Very hard
	Pump Internals Rebuild	Easy	Very hard

Table 3 : Comparison of APR1400 and AP1000

Benefit Doesn't Work for APR1400 RCP

1) VFD is used only for MODE 6 (Refueling).
- MODE 1, 2 (Power Output) cannot be used
If adopted, all of the safety issues should be reviewed.
2) Cannot expect energy savings with high efficiency motor.
3) Start up duration is not long and frequency is very rare.
4) No need for bigger flywheel. APR1400 has already been designed to endure at the current circumstance.
5) Smaller motor with VFD has almost the same efficiency characteristics, compared with current motor.
6) Short-circuit duty improvement works only on some cases.
7) VFD adds to system cost.
8) Needs step up transformer for 13.8kV motor.

Canned motor (AP1000) using VFD has some benefits. The benefits don't justify the cost of the application on the APR1400. It already has its own robust system, which is optimized to other related parts or systems.

Recommendation and Future Study

Recommendation for APR 1400

To enhance the safety related to a leakage of motor's seal in case of LOOP (Loss of Offsite Power), SB-LOCA (Small break Loss of Coolant Accident), and SBO (Station Black Out), shutdown seal can be considered for APR1400 RCP.

Future Study : Need to consider the application of VFD to Condensate or Circulating Pump motors which may require accurate flow control frequently.