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Real time simulation of Variable Speed Parallel Pumping system

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Abstract

Energy is the world's fundamental requirement to perform any work. Presently, insufficiency in energy is the major challenge faced throughout the world. Among the total installed loads, pumping contributes, 30% of them. Thus considerable improvement in energy savings is possible by increasing the energy efficiency of the pumping system. Nowadays, the usage of variable frequency drives (VFDs) for pumping system is becoming inevitable due to their control over flow rate variation. This paper presents the performance of real time simulated variable speed multi pumping system. The variable speed pumps using affinity laws reduces power up to 80% when there is a reduction in speed of 50%. The efficiency of the pumping system is identified by incorporating the efficiency of both motor and the variable frequency drive (VFD).

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Keywords: Affinity Laws, Centrifugal pumps; Efficiency calculation; Parallel pumps; Real-time simulation; Variable speed drives.

1. Introduction

Among the total energy demand in the industries, nearly one quarter to half of them are due to pumping system [1]. However, centrifugal pumps contribute 80% of the total pumps installed in buildings and industries [2]. Normally, energy efficiency of the pumping system can be improved by component selection, optimal design and the control algorithm used [3]. With optimal system design and control methods, energy efficiency of around 5% -

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50% can be achieved [4]. Moreover, regular maintenance and proper component selection results in 1% - 3% of increase in efficiency [5], [6].

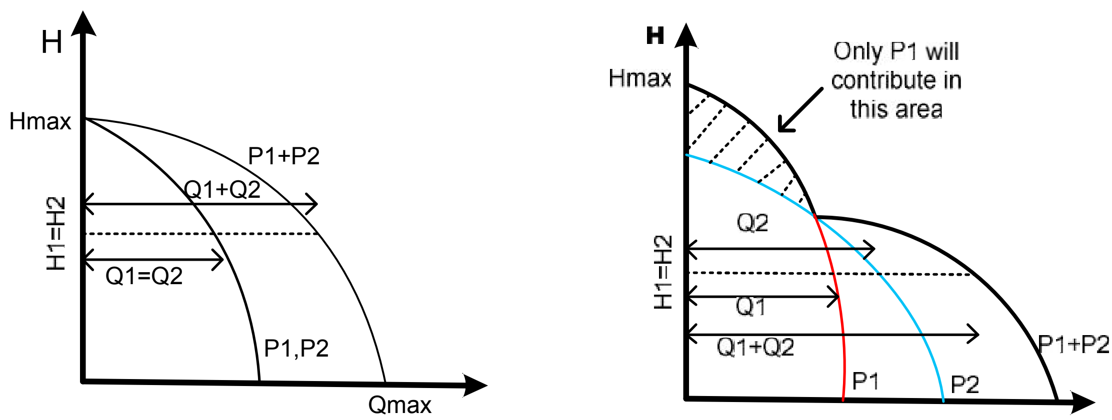
Nomenclature

Abbreviations		Superscripts/ Subscripts	
N	Rotational Speed of pump [rpm]	1	Initial value
Q	Flow rate [m3/hr]	2	Estimated value
H	Head developed [m]	s	Specific energy
ρ	Liquid density [kg/m3]	sys	Pumping System
g	specific gravity	in	Input
P	power drawn [W]	tot	Total input
V	Volume of liquid [m3]	i	Number of Parallel pumps
D	Pump impeller Diameter [mm]		
E	Energy consumption		
t	Time [sec]		
VFD	Variable Frequency Drive		
η	Efficiency [%]		

Replacing conventional valves by variable frequency drives for pumping systems benefits like, energy savings of nearly, 30% - 50%, increased process control and system reliability are achieved [7]. In this article the real time simulation of parallel pumping system is realized using PLECS. The variation of pumping parameters (i.e., flow rate and pressure) for different rotational speeds is observed. Also the total system efficiency exhibited by the entire pumping system is illustrated from the simulation results.

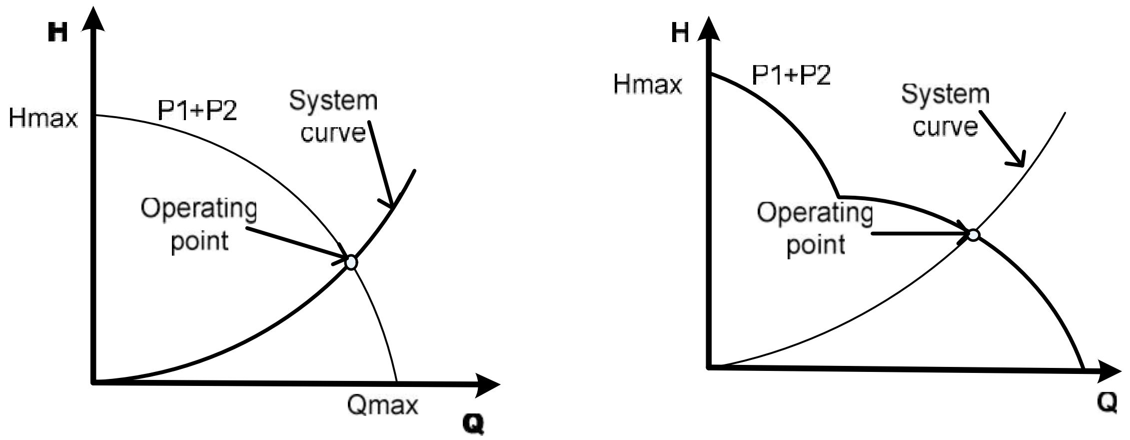
2. Performance curve of pumps

The curve drawn between flow rate (Q) and head (H) characterizes the performance curve of the pump. In industries, the usual practice is to commission two or more smaller pumps instead of a large single unit. The pumping units has to be connected appropriately (either in series or parallel) depending on the process demand. The flow rate gets added with the pump head remains constant when the pumps are added in parallel as shown in Fig. 1.



(a) Induvidual pump performance curves (Similar pumps)

(b) Induvidual pump performance curves (Dissimilar pumps)



(c) Resultant performance curve with system curve (Similar pumps)

(d) Resultant performance curve with system curve (Dissimilar pumps)

Fig. 1. Parallel connected pumps - Performance curves[8]

The characteristic property of centrifugal pumps is affinity laws [9]. It states the relation between the flow rate, head, power drawn of the pump and the motor speed. Thus from equation (1), reduction in speed by 30% results in the reduction of power consumed by 66%.[10], [11]

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \tag{1}$$

3. VFD Control

The speed of the AC motor is controlled by using variable frequency drives that converts fixed frequency to variable [12]. Highly efficient and reliable VFDs are available for the pumping system due to the development in the field of power electronics. In other words, energy consumption reduces by 20%when the VFDs are used to do the same work that is done by conventional valve control [13], [14]. The block diagram of the parallel pumping system considered is shown in **Fig. 2**.

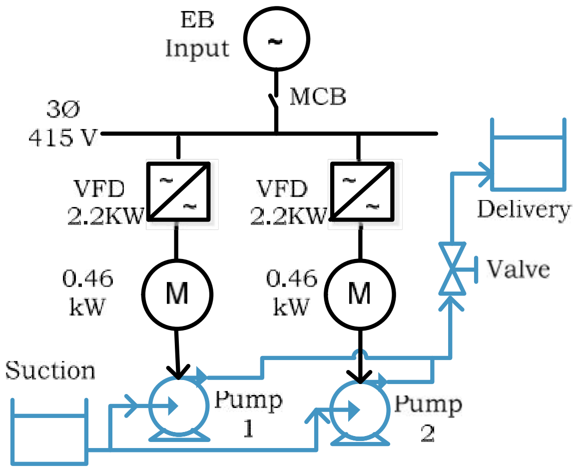


Fig. 2. Multi pump system connected in parallel

The parallel pumping system with induction motor and centrifugal pumps are modeled and simulated in the Matlab-PLECS environment as shown in Fig. 3.

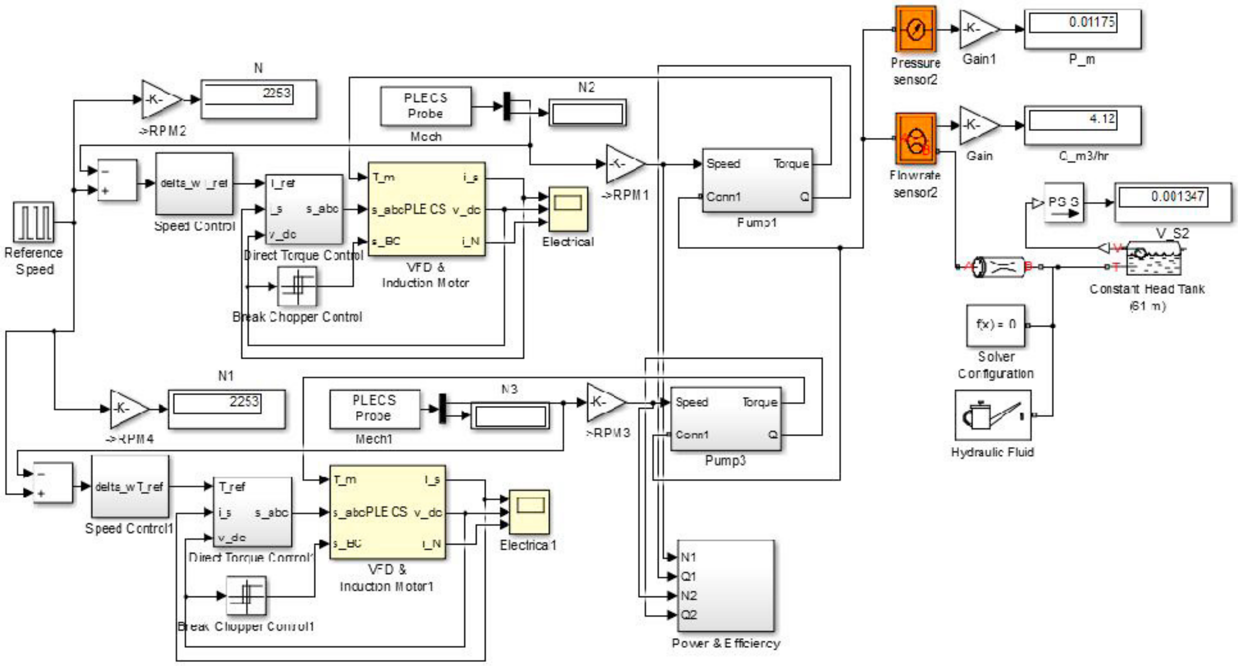


Fig. 3. PLECS modelling- Parallel pumping system

For the PLECS simulation, pump capacity of 0.46kW is considered with the VFD having 2.2 kW. The motor parameters considered for the modeling is shown in Table 1.

Table 1 System Parameters

Parameter	Value	Parameter	Value
Rated Voltage	415 V	Stator Resistance	0.1602 Ω
Rated Frequency	50 Hz	Rotor Resistance	0.0764 Ω
Ploe pair	1	Stator Inductance	0.5689 mH
Rated capacity	0.46 kW	Rotor Inductance	0.5689 mH
Moment of Inertia	2.80 Kg-m2	Mutual Inductance	0.0155 H

The step response for speed in DTC fed induction motor for pumping system is shown in **Fig. 4**. The variation of the individual pump rotational speed from 2235 rpm to 2253 rpm is observed. The actual speed of the motor follows the reference set speed. The manufacturer's datasheet provides the rated flow rate and the pressure of the pumps. The pumps are recommended to operate near the rated flow rate in order to attain maximum efficiency.

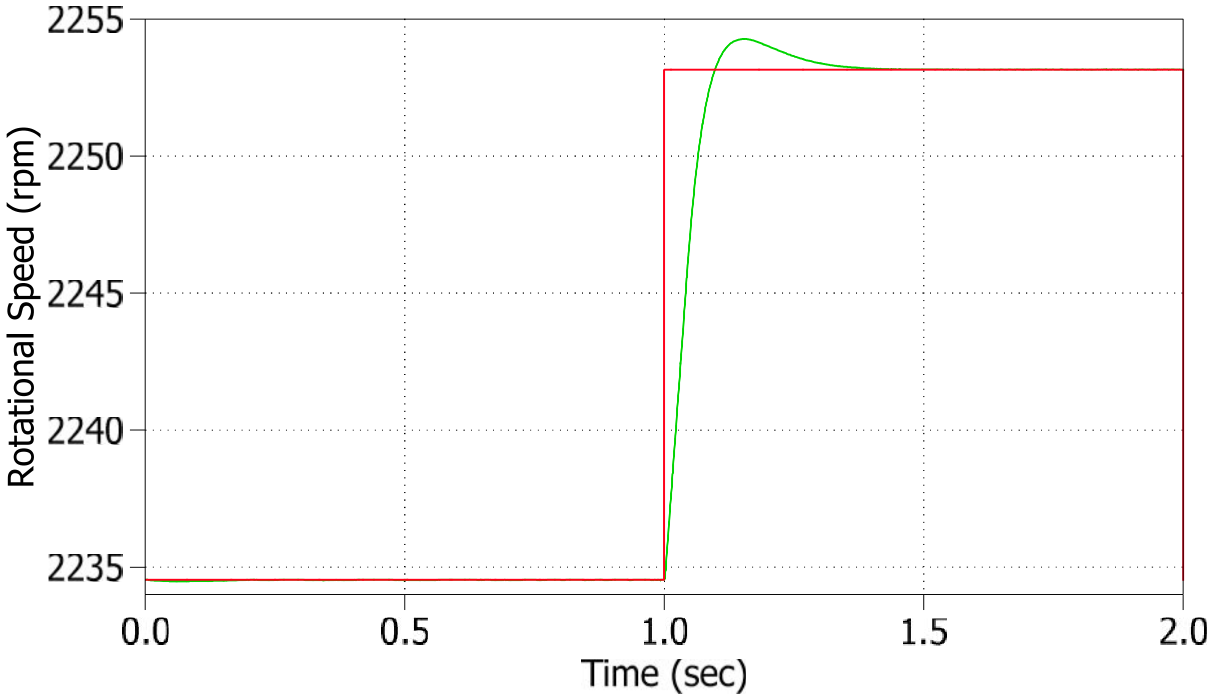


Fig. 4. Motor rotational speed

With the variation in the rotational speed, the pump output parameters, flow rate and pressure are varied accordingly. Fig. **5** shows the combined flow rate and the pressure exhibited by both the pumps connected in parallel.

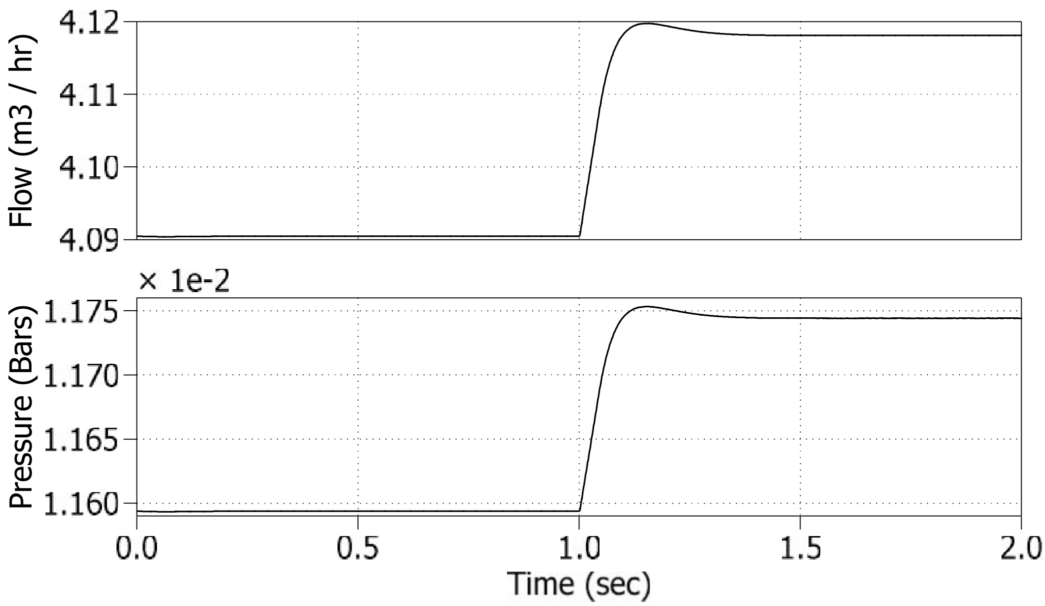


Fig. 5. Pump output parameters

The performance of the pumping system is measured using the system efficiency as shown in Fig. 6. The system efficiency for the parallel connected pumps is the product of efficiency of the pump and the VFD. However, specific energy is used for measuring the effectiveness of the parallel pumping system as shown in equation (2) and (3).

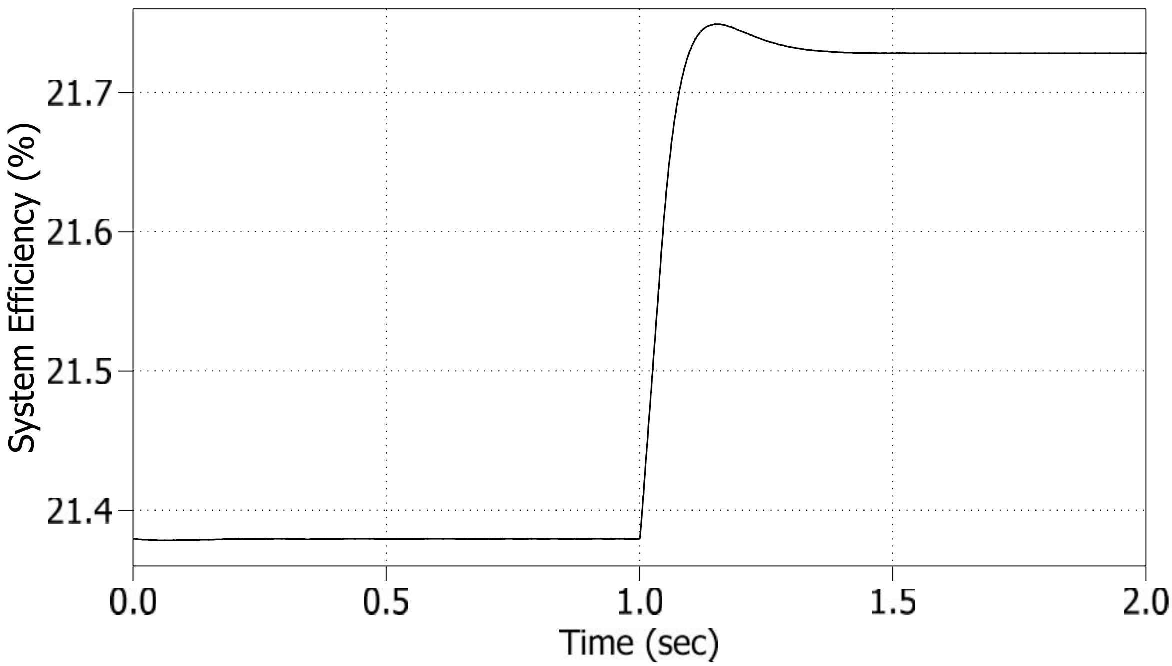


Fig. 6. System Efficiency

The specific energy is calculated for the pumping system with single pumps and the multiple pumps as per equation (2) and (3).

$$E_s = \frac{P_{in} \cdot t}{V} = \frac{P_{in}}{Q} = \frac{\rho \cdot g \cdot H}{\eta_{sys}} \tag{2}$$

$$E_S = \frac{P_{in,tot}}{Q_{tot}} = \sum_{i=1}^{n} \frac{\rho g \cdot H_i}{\eta_{sys,i}} \tag{3}$$

4. Conclusion

In this paper, modeling of variable speed parallel pumping system is done in PLECS environment. The relation between the rotational speed and pump parameters is provided by affinity laws of centrifugal pumps. When the pumps are connected in parallel, the change in various pump output parameters (total flow rate and pressure of the pumping system) with respect to the change in rotational speed is discussed. However the performance of pumps is measured through system efficiency of the individual pump units that are connected in parallel. The servo response of pumping system efficiency and the pump parameters with respect to change in pump speed is observed.

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