International Journal of Theoretical & Applied Sciences, 13(2): 17-21(2021)

ISSN No. (Print): 0975-1718
ISSN No. (Online): 2249-3247

Evaluation of Energy Conservation Potential of Soft Starter Aided Electrical Motor Applied for Dairy Industry

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(Received 07 July, 2021, accepted 13 September, 2021)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Electricity is the most vital utility used for any goods and service providing industry now-a-days. Electric motors are staple of industrial applications due to its distinct features like low cost, sturdy construction, high efficiency, and good power factor. Mostly induction motors are used to convert electrical energy into mechanical output. Over the times, three phase general purpose motors have established an uncanny knack for providing a plethora of utilities on the go. To operate three phase induction motor, it requires a starting device called a starter. In present study, a three phase induction motor widely utilized in dairy processing was operated with soft starter under different load conditions and load cycles/hr. It was very difficult to measure the effect of variable load on energy consumption of motor which requires a suitable load varying mechanism, but with a few engineering interventions in experimental set-up it has been possible to operate the motor under variable load pattern. A soft starter was utilized against a conventional Direct on Line (DOL) starter to operate three phase induction motor for different equipment set-ups. The experimental data reveals that the soft starter used to operate the motor has given instantaneous energy saving in the range of 6.35-8.00%, 4.38-10.31% and 6.00-11.19% for 5, 10 and 20 on-off cycles per hour at no load condition of motor respectively with different experimental set-ups. Similarly, it has given 5.78-9.68%, 4.00-10.58% and 6.95-11.00% energy saving for 5, 10 and 20 on-off cycle/hr at partial load condition of motor over different experimental units respectively. However, the motor operated with the soft starter at full load condition gave the highest energy saving of 6.22-12.82%, 9.00-16.35% and 10.20-17.16% for 5, 10 and 20 on-off cycles per hour respectively. The experimental data were statistically analyzed by the 2 factor analysis on 5% level of Significance. Based on the present investigation we can conclude that application of the soft starter for three phase industrial motors used in dairy industry can save the electrical power, and also help to improve the power factor.

Keywords: Soft starter, Novel starting methods, Energy conservation in Dairy Industry, Energy Saving, Motor starting device, Motor Voltage Control.

I. INTRODUCTION

Over 75% of the mechanical power harnessed by industries is due to three phase induction motors having specific features like good speed regulation, operating characteristics and sheer absence of commutators [1]. Additionally, three phase motors cost considerably less than single phase motors (approx. 30-50 per cent) also provides large range of horsepower size [2]. To operate any three phase motor, it requires a power supply unit called a starter. Conventional Direct on Line starter is widely used to operate the Squirrel cage induction motor, which can serve to the limited small frame size motors [3]. Star-Delta starter is a good alternative to operate medium to frame size motors. As the Indian Dairy Industry is expanding rapidly, to keep pace with the higher milk production rate, Indian Dairy Industry has been transformed to automated plant operation over the conventional production system. Three phase induction motor, when started from static with full voltage impressed, the starting current is 5 to 8 or more times the rated current. The large line current drawn by such a motor is intolerable because of the possible sharp drop in voltage of the supply circuit and undesired effects upon other connected devices [4]. Due to the high end sensor based automated production process in the dairy industry, the frequent on-off cycle of the induction motor may consume high in-rush current. Moreover, too many on-off cycles of motor operation in dairy processing leads to decrease in the life of the motor and equipment.

An operation of a large induction motor with a direct on line (DOL) starter poses a great problem to the grid as well as the motor itself due to sudden voltage dips and huge fluctuating torque [5, 6]. Sometimes due to tripping of under-voltage and overload relays, the motor may fail to start [7]. To solve such an issue, a reduced starting voltage is being used especially for starting large induction machines using autotransformers. However, the volume and the cost of auto-transformers limit its application [8].

Power Electronics converter based induction motor starters, usually called soft starters, are becoming popular and rapidly replacing the conventionally used reduced voltage starters using auto-transformers [9, 10]. The initial inrush current of motor can be reduced significantly by starting of a motor using power electronics converter based starting [11]. Starting the motor with a soft starter offers smooth acceleration, ease in execution of current control, and energy savings with a partial load can be available [12, 13].

The initial starting torque at the standstill of an induction motor is proportionate to the square of the applied voltage. It surely affects the starting of induction motor upon load condition. Furthermore, the output voltage quality is poor with high distortion and poor power factor. Application of the soft starter results a good acceleration profile, smooth pulsation free torque, during entire starting period [14, 15]. A very scanty research data is available for the performance evaluation of the different motor starting devices used for the operation of the three phase induction motor. Present work is emphasized to evaluate the energy conservation potential and performance of the motor on various load conditions by using a soft starter with following objectives:

- To compare the energy conservation potential of soft starters with conventionally used starters.
- To evaluate the performance of the soft starter under various load conditions.
- To optimize the operating conditions of the motor with a soft starter.

II. MATERIALS AND METHODOLOGY

The experimental assembly consisting of three phase electrical motor, DOL starter (conventional starter), soft starter, change over switch as well as arrangement for load variation was developed in the laboratory (Fig. 1). The necessary electrical measuring devices such as power analyzer, energy meter and power factor meter etc. also installed for the measurement of operating variables. Experimental trials were carried out to evaluate the performance of the soft starter and the energy saving potential of the soft starter under different load conditions.

Experimental set-up I | Experimental set-up II | Experimental set-up III

Fig. 1. Pictorial representation of the experimental set-ups.

The experimental assembly was utilized for three different experimental set-ups under various load conditions. Specification of the motors used in Experimental Set up is mentioned below in Table 1.

Table 1: Specification of the motor utilized in experimental set-up.

Parameters	Set up 1	Set up 2	Set up 3
kW/Hp	2.2/3.0	0.75/1	1.5/2
Ampere	4.8	1.85	3.2
Voltage	415	380	440
Phase	3	3	3
Rpm	2880	1455	1440
Insulation Class	B	B	B

Variable Parameters: Present work has been undertaken to evaluate the energy conservation potential and performance of the motor under various load conditions through application of a soft starter. Here, the performance of soft starter was compared with conventional DOL Starter under different motor load conditions, like no-load condition, partial load Condition and Full load condition. Considering the higher number of on-off cycles of the motor during dairy processing operations, the motor performance was also evaluated based on the number of on-off cycles like 5 on-off cycle/h, 10 on-off cycle/hand 20 on-off cycle/h. Based on the experimental trials, the resultant data of the experiments Voltage (V), Current (A), Energy Consumption (W) and power factor (Cos ϕ) were noted and assessed for the energy saving potential over the conventional starter. The data collected during the experimental trials were analyzed by CRD design.

III. RESULT AND DISCUSSION

A three phase induction motor aided with a soft starter was connected with a panel board containing all essential electrical accessories like 3 phase Power Analyzer, Voltmeter, A meter, etc. Two different types of starters i.e. DOL (S_1) and Soft Starter (S_2) were used to operate the motor at 5(O_1), 10 (O_2) and 20 (O_3) on-off cycle/h at no-load condition (L_1), partial load condition (L_2) and full load (L_3) conditions of motor respectively. The experimental parameters like current, voltage, power and power factors of all three experimental set-ups operated by DOL starter and Soft starter with three replications were analyzed through 2 factor CRD design at a 5% level of significance. Effect of variable parameter on current consumption, voltage utilization and energy consumption data were represented in tables given below (Tables 2-4).

A. Effect of variable parameters on energy consumption of motor at Experimental set-up I

In present study, the hydraulic mono-block pump having three phase induction motor was operated by soft starter. Such types of hydraulic pumps are widely used in dairy processing. The energy consumption and other parameters of the experimental unit were recorded as shown in Table 2.

Table 2: Factorial analysis of energy consumption data of Experimental Set-up 1 under various load patterns.

	Current (A)			Voltage(V)			Power (W)			Power factor COS ϕ		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
S_1	7.455	7.437	11.04	403.967	404.478	407.989	4.016	4.075	5.192	0.7684	0.7826	0.6673
S_2	6.987	7.040	7.34	396.478	399.556	403.211	3.658	3.822	4.523	0.7597	0.7855	0.8880
S.Em.	0.018	0.011	0.019	0.361	0.099	0.137	0.010	0.013	0.016	0.001	0.00	0.003
CD	0.057	0.035	0.059	1.113	0.305	0.421	0.032	0.041	0.051	0.003	0.00	0.004
O_1	7.208	7.21	9.1667	399.633	402.350	405.667	3.946	3.963	4.808	0.7848	0.7881	0.7729
O_2	7.246	7.23	9.193	400.883	402.116	404.983	3.806	3.920	4.877	0.7558	0.7894	0.7778
O_3	7.210	7.26	9.216	400.150	401.266	406.150	3.760	3.963	4.888	0.7516	0.7775	0.7823
S.Em	0.022	0.014	0.023	0.442	0.121	0.167	0.13	0.016	0.020	0.001	0.00	0.004
CD	NS	NS	NS	NS	0.374	0.516	0.039	NS	0.062	0.003	0.001	NS
CV%	0.76	0.47	0.63	0.27	0.07	0.10	0.81	1.0	1.01	0.32	0.06	1.22
SO	*	NS	NS	*	*	*	*	*	*	*	*	*

Experimental trials on hydraulic mono-block pump revealed that the use of soft starter at no-load conditions saves 8.63%, 7.50% and 10.32% instantaneous electrical power at 5, 10 and 20 on-off cycles/h operating conditions respectively. Operation of an electric motor at 50% load condition with soft starter has given an instantaneous saving of 6.89%, 4.07% and 7.60% at 5, 10 and 20 on-off cycles/h operating conditions respectively. Use of soft starter at full load condition saved 9.37%, 13.27% and 14.48 % instantaneous electrical power at 5, 10 and 20 on-off cycles/h operating conditions respectively.

B. Effect of variable parameters on energy consumption of motor at experimental set-up II

In present study, the Scraped Surface Heat Exchanger (SSHE) having scraper and driving assembly attached with the motor was operated with soft starter containing experiment unit. In many dairy operations, basically milk is converted into milk product batch; during such operations the viscosity of milk (responsible for motor load) is increased with increasing concentration of milk. That was the basic rationale behind the selection of SSHE for the experimental unit II. The set-up was run under different variable load conditions and observations were recorded in Table 3.

Table 3: Factorial analysis of energy consumption data of the Experimental Set-up II under various load patterns.

	Current (A)			Voltage(V)			Power (W)			Power factor COS ϕ		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
S_1	5.740	9.3667	9.4956	407.733	389.977	390.722	1.9396	3.6502	3.6186	0.5784	0.5784	0.5876
S_2	4.991	8.2689	8.0667	407.744	388.367	387.215	1.7538	3.2690	2.8743	0.5810	0.5810	0.5803
S Em	0.021	0.026	0.015	0.131	0.200	0.155	0.001	0.009	0.005	0.000	0.00	0.00
CD	0.064	0.081	0.046	NS	0.617	0.479	0.004	0.027	0.014	0.001	0.001	0.00
O_1	5.263	9.0417	9.025	406.546	388.65	389.483	1.7954	3.5258	3.465	0.5798	0.5798	0.5902
O_2	5.380	8.7500	8.655	408.700	389.25	389.387	1.8713	3.4685	3.403	0.5794	0.5794	0.5774
O_3	5.453	8.6617	8.663	408.00	389.616	388.775	1.8735	3.3845	2.8707	0.5800	0.5800	0.5844
S Em	0.025	0.032	0.018	0.160	0.245	0.190	0.002	0.011	0.006	0.00	0.00	0.00
CD	0.078	0.099	0.057	0.494	0.755	0.586	0.005	0.032	0.017	NS	NS	0.00
CV%	1.15	0.89	0.52	0.10	0.15	0.12	0.20	0.75	0.42	0.52	0.19	0.04
Int.SO	*	*	NS	*	NS	*	*	NS	*	*	*	*

Experimental trials on SSHE with load varying mechanism reveals that the use of soft starter at no-load conditions results in 6.34 %, 10.31 % and 11.91% instantaneous electrical power saving at 5, 10 and 20 on-off cycles/h operating conditions respectively. Operation of the electric motor at 50% or partial load condition with soft starter gave an instantaneous saving of 9.68 %, 10.58% and 11.02 % at 5, 10 and 20 on-off cycles/h operating conditions respectively. Use of soft starter at full load condition saves 12.877%, 16.35% and 17.16% electrical power at 5, 10 and 20 on-off cycles/h operating conditions respectively.

C. Effect of variable parameters on energy consumption of motor at experimental unit III

Some of the dairy operations deal with cutting or milling of semi-solid to a solid mass, which requires having a good impact load. Experimental unit III represents such dairy operations and the performance of motor under such conditions. The set-up was run under different variable load conditions and observations were recorded in Table 4.

Table 4: Factorial analysis of energy consumption data of the Experimental Set-up II under various load patterns.

	Current (A)			Voltage(V)			Power (W)			Power factor COS ϕ		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
S_1	7.3811	7.463	7.544	407.322	408.70	409.56	4.005	3.820	3.945	0.7709	0.7224	0.7458
S_2	6.9386	7.0078	7.026	402.078	405.123	405.96	3.772	3.577	3.642	0.7804	0.7278	0.7383
S Em	0.015	0.021	0.028	0.242	0.123	0.100	0.010	0.010	0.016	0.00	0.00	0.001
CD	0.045	0.064	0.086	0.746	0.379	0.309	0.030	0.029	0.049	0.001	0.001	0.002
O_1	7.145	7.225	7.215	405.1	407.10	407.68	3.964	3.628	3.796	0.7928	0.7118	0.7422
O_2	7.171	7.253	7.285	404.117	406.72	407.2	3.8285	3.717	3.804	0.7626	0.7272	0.7399
O_3	7.1637	7.228	7.220	404.883	406.91	408.38	3.8718	3.750	3.783	0.7715	0.7363	0.7442
S Em	0.018	0.025	0.034	0.297	0.151	0.123	0.012	0.012	0.020	0.001	0.00	0.001
CD	NS	N	N	0.746	N	0.379	0.037	0.036	NS	0.002	0.01	0.003
CV%	0.62	0.86	1.16	0.18	0.09	0.07	0.75	0.78	1.26	0.19	0.16	0.27
Int.SO	NS	NS	NS	NS	*	*	*	N	*	*	*	*

Experimental trials on Drilling machine with load varying mechanism revealed that use of soft starter at no-load conditions results in 7.247%, 4.388% and 6.069% instantaneous electrical power saving at 5, 10 and 20 on-off cycles/h operating conditions respectively. Operation of an electric motor at 50% load condition with soft starter gave an instantaneous saving of 5.78%, 6.05% and 6.95% at 5, 10 and 20 on-off cycles/h operating conditions respectively. Use of soft starter at full load condition soft starter saves 6.22%, 6.57%, and 10.20% instantaneous electrical power at 5, 10 and 20 on-off cycles/h operating conditions respectively.

Similar type of the comparative study was done by many researchers to start the 3 phase motor with star-delta starter. One of the researcher [4] tried new approach to start poly phase induction motors without using any primary voltage compensators thereby limiting the inrush of starting current. They found that the starting current is reduced by 50% to75% depends on the speed at which rotor is driven. The starting current took only 2 to 2.5 cycles to attain steady state whereas it require 5 cycles with star delta type starting mechanism to reach steady state. Furthermore, they found that it reduces system voltage disturbance and reduced adverse effect on the connected loads, thus maintaining the quality of the supply. Owing to the above observations the proposed method of starting can be effectively used [15].

IV. CONCLUSION

Three phase Induction motors are most widely used in industries than other machines due to their advantages such as simplicity in construction, reliability in operation, and cheapness. It is recommended to use a soft starter against a conventional Direct on Line starter to operate three phase induction motor for different operating conditions. The soft starter gives energy saving in the range of 6.35-8.00%, 4.38-10.31% and 6.00-11.19% for 5, 10 and 20 on-off cycle/h at no load condition of motor respectively. Similarly, it gives 5.78-9.68%, 4.00-10.58% and 6.95-11.00% energy saving for 5, 10 and 20 on-off cycle/h at partial load condition of motor respectively. However, the motor operated with a soft starter at full load condition gives the highest energy saving of 6.22-12.82%, 9.00-16.35% and 10.20-17.16% for 5, 10 and 20 on off-cycle respectively. However, these energy saving values are for the instantaneous power consumed upon the starting of the motor, which reduces the risk of the voltage drop in the system. It is also concluded that energy saving potential is increased with increasing the number of on-off cycle/h. During the present investigation, it was found that the application of a soft starter for motor operation helps to improve the power factor and also limits the inrush current upon starting of the motor which helps to improve the life span of the motor operation.

V. FUTURE SCOPE

In Present era, many novel starting devices and modern strategies coming out to start the three phase induction motor. Among all of these, Variable Frequency Drive (VFD) or AC drives become more popular in dairy processing. The performance evaluation and characteristic of motor operated with VFD needs to evaluate for the power saving potential. Furthermore, the performance of the different motor starting devices can be compare with different frame size motors under variable load.

Acknowledgement. I wish to thank all the people whose assistance was a milestone in the completion of this project. I express my special thanks of gratitude to my teacher as well as our principal who gave me the golden opportunity to do this wonderful project.

Conflict of Interest. The authors whose names are listed in this research paper have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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