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Use Fuzzy Rules and Experimental Design to Predict and Improve Output Performance of Three-Phase Inductive Motor

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ABSTRACT: Surface design and Fuzzy logic used to find the best performance for three phase inductive motor. Three factors, voltage, power factor, and current used as inputs and two responses are exploited power P and apparent power S used as dependents. First, thefuzzy logic used to extract 13 rules to predict the output. However, as soon as rules ready the values of apparent power S and real exploited power can be changed according to any change in the input variables but without understanding the real action in the process. The surface design used to enhance and diagnosis these rules in experimental form. In anattempt to modify fuzzy rules in experimental design, independent factors or left hand taken without any change but in dependent responses or right hand, electrical power equations used to get the exact response for understanding the whole process according to experimental design then it validated by thetesting machine. Fuzzy logic follows IF THEN statement but in thedesign of experiment to mimic these rules; the same conception will be used by classifying the response or output to low and high levels according to the required design. For exploited power, values equal or less than 1497.96 W classified as low level and values of equal or greater than 1539W classified as high level, whereas, in apparent power, values equal or less than 1620 VA classified as low level and values equal or greater than 3942 VA classified as ahigh level. For two responses, Apparent power S did not give significant results because of standard errors equal to zero and observed values equal to predicted values. Therefore no residual values found in theresults. However, from theresponse of real exploited power P, power factor and current have a very significant important and interactions as well, whereas, voltage factor gavethe lowest significant and bad interaction between current or power factor. Paper concluded that to improve theperformance of machine power factor can be improved by modifying thecurrent variable.

KEYWORDS, Fuzzy logic, experimental design, three-phase inductive motor, electrical equations

I.INTRODUCTION

In industry field, machines play a vital role in production and manufacturing. Most of the electrical loads in Libyan industry field are inductive loads; this means a power factor is leading, and waste power will be changed according to power factor values. Power factor might be lagging or leading according to loads characteristics. To decreasepower waste, we must improve power factor value. If current andvoltageare in one path, then power factor COS 0 will be 1 and waste will be zero because of real exploited power P is equal to apparent power S.

In this study, power factor supposed to use as a response but it selected as a factor to build a design that gives high energy output by respecting values of current and voltage. When machine works, we have to build many rational guesses. Fuzzy logic is a good method to build rules that relate to real machine situation. Three phase inductive motor has been selected to study machine characteristics and find the optimum performance according to the study of theoutput of fuzzy rules, main effect, and a significant interaction between factors.

Cyclic maintenance might help to keep a performance of machines in good rank and accepted productivity. Sometimes cyclic maintenance isconducting in the insufficient way, then some technical faults likethe waste power may be exposed. Two real problems in the study. First, most of the machines in Libyan industries company are old and second; no professional maintenance is doing in thesuitable cyclic period, instead of maintenance, emergency repairs are conducted assoon as the fault is exposed. One machine selected to do some experiments, but it’s performance is very low, andit has a low response as well because it is different between apparent power and real exploited power. This paper predicted the output using fuzzy logic and experimental design used to diagnosis extracted rules by getting the main effects and interactions.By manipulating in the rules, many results for P and S but this is not enough to understand the process and get the improvements. the experimental design selected as a good tool to understand themachine and find the best factor which makes the improvements.

II.PROBLEM STATEMENT

Machines in Libyan factoriesare slow and old. There is a big gap between real or exploited power (P) and apparent power (S) led to a big waste ofthe energy. Power factor (PF) is very important factor to reduce waste power and improve theefficiency of machines.The fuzzy logic used to predict output and experimental design used to diagnosis rules in experimental form.

III. METHODOLOGY

1- Extract rules using fuzzy logic voltage, Current, and Power factor as factors or inputs and apparent power, and real or exploited power as responses or dependents). Build membership function to predict the outputs.
2- Electrical equations for apparent power and exploited power used to find output mathematically and validate data using thereal machine.
3- Use experimental design to diagnosis these rules in experimental form and study the main effects and interactions(design constructed according to the same rules).
4- Use (central design, non-factorial, surface design) to solve selected design.

Figure 1 shows the methodology of study

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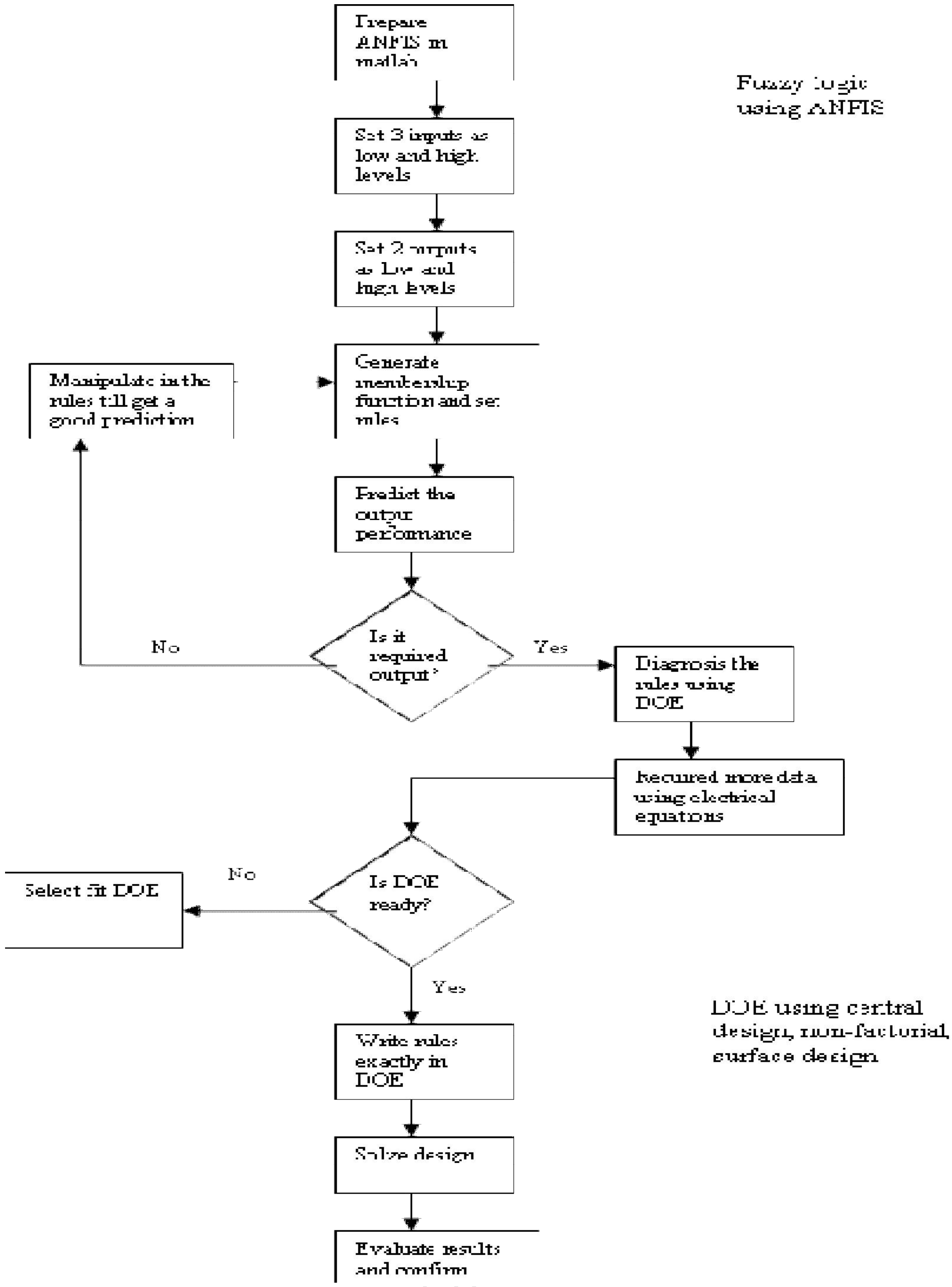

Figure1, methodology to improve output

IV.FUZZY RULES USING MATLAB

We built 13 rules from 3 inputs (current (I), voltage (V), and power factor (PF) and 2 outputs (apparent power and exploited power) as following: -

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Name='power_factor'
Range=[0.3 0.95]
NumMFs=2
MF1='LOW':'trimf',[0.0434428571428572 0.303542857142857 0.563542857142857]
MF2='HIGH':'trimf',[0.691719576719577 0.951719576719577 1.21171957671958]
[Input2]
Name='current (I)'
Range=[2.4 6]
NumMFs=2
MF1='LOW':'trimf',[0.950095238095238 2.39009523809524 3.83009523809524]
MF2='HIGH':'trimf',[4.55952380952381 5.99952380952381 7.43952380952381]
[Input3]
Name='voltage (V)'
Range=[657 675]
NumMFs=2
MF1='LOW':'trimf',[649.466666666667 656.666666666667 663.866666666667]
MF2='HIGH':'trimf',[667.847619047619 675.047619047619 682.247619047619]
[Output1]
Name='apparent_power'
Range=[486 3848]
NumMFs=2
MF1='LOW':'trimf',[-876.577777777778 468.522222222222 1812.22222222222]
MF2='HIGH':'trimf',[2547.75661375661 3892.75661375661 5236.75661375661]
[Output2]
Name='exploited_power'
Range=[1620 4050]
NumMFs=2
MF1='LOW':'trimf',[648.042857142857 1620.14285714286 2592.14285714286]
MF2='HIGH':'trimf',[3080.71428571429 4060.71428571429 5030.71428571429]

V. EXTRACTED RULES USING MATLAB

IF (Power factor (PF) is LOW) (current (I) is LOW) and (voltage (V) is LOW) then (apparent power is LOW) (exploited power is LOW)
IF (Power factor (PF) is LOW) (current (I) is HIGH) and (voltage (V) is LOW) then (apparent power is HIGH) (exploited power is LOW)
IF (Power factor (PF) is LOW)(current (I) is HIGH) and (voltage (V) is HIGH) then (apparent power is HIGH)(exploited power is LOW)
IF (Power factor (PF) is HIGH) (current (I)is LOW) and (voltage (V) is LOW) then (apparent power is LOW) (exploited power is LOW)
IF (Power factor (PF) is HIGH) (current (I) is HIGH) and (voltage (V) is LOW) then (apparent power is HIGH) (exploited power is HIGH)
IF (Power factor (PF) is HIGH) (current (I)isHIGH)and(voltage (V)isHIGH)then(apparent powerisHIGH) (exploited powerisHIGH)
IF (Power factor (PF) is HIGH) (current (I)is LOW) and (voltage (V) is HIGH) then (apparent power is LOW) (exploited power is HIGH)
IF (Power factor (PF) is LOW) (current (I)is LOW) and (voltage (V) is HIGH) then (apparent power is LOW) (exploited power is LOW)
IF (Power factor (PF) is LOW) (current (I)is HIGH) and (voltage (V) is HIGH) then (apparent power is HIGH) (exploited power is LOW)
IF (Power factor (PF) is HIGH) (current (I)isLOW)and(voltage (V)isLOW)then(apparent powerisLOW) (exploited powerisLOW)

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IF (Power factor (PF) is HIGH)(current (I)isHIGH)and(voltage (V)isLOW)then(apparent powerisHIGH)(exploited powerisHIGH)
IF(Power factor (PF) is HIGH) (current (I)isHIGH)and(voltage (V)isHIGH)then(apparent powerisHIGH)(exploited powerisHIGH)
IF (Power factor (PF) is HIGH) (current (I)isLOW)and(voltage (V)isHIGH)then(apparent powerisLOW)(exploited powerisHIGH)

VI. CENTRAL DESIGN, NON-FACTORIAL, SURFACE DESIGN

Now, build experimentaldesign with the same rules to diagnosis predicted output performance.the design of experiment (central design, non-factorial, surface design), but some considerations must be taken bygetting the real responses for right-hand rules then classify them low and high level according to the response values.

Factors			Responses	
Power factor (PF)PF	**Current (I) I**	**Voltage (V) V**	**Exploited power P**	**Apparent power S**
0.3	2.4	657	473.04	1576.8
0.3	6	657	1182.6	3942
0.3	6	675	1215	4050
0.95	2.4	657	1497.96	1576.8
0.95	6	657	3744.9	3942
0.95	6	675	3847.5	4050
0.95	2.4	675	1539	1620
0.3	2.4	675	486	1620
0.3	6	675	1215	4050
0.95	2.4	657	1497.96	1576.8
0.95	6	657	3744.9	3942
0.95	6	675	3847.5	4050
0.95	2.4	675	1539	1620

Table 1 Design of experiment with two responses

Values of apparent power and exploited power found using equations of
$P = V * I * COS\theta$………..(1) for exploited power.And
$S = V * I$ …................(2) for apparent power.
And validated using real testing of selected machine.

VII. RESULTS AND DISCUSSION

We did not get any effect from S or apparent power response because of observed values equal to predicted values and no residuals found, then standard errors equal to zero. Thus, we focused the solution on P or real exploited power as output to evaluate interactions and main effects.
Effect Estimates;Var.:P; R-sqr=.99998; Adj:.99997
3 factors, 1 Blocks, 13 Runs; MS Residual=53.76044
DV: Exploited power P

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Factor	Effect	Std.Err	t(6)	P	-95.% Cnf.Lim	+95.% Cnf.Lim	Coeff.	Std.Err Coeff.	-95.% Cnf.Lim	+95.% Cnf.Lim
Mean/interact	1747.771	2.140527	816.5146	0.000000	1742.534	1753.009	1747.771	2.140527	1742.534	1753.009
(1) PF(L)	1819.137	4.281054	424.9275	0.000000	1808.662	1829.613	909.569	2.140527	904.331	914.806
(2) I (L)	1497.543	4.281054	349.8070	0.000000	1487.067	1508.018	748.771	2.140527	743.534	754.009
(3) V(L)	9046.293	4.281054	10.8134	0.000037	35.817	56.768	23.146	2.140527	17.909	28.384
1L by 2L	780.177	4.281054	182.2395	0.000000	769.702	790.653	390.089	2.140527	384.851	395.326
1L by 3L	25.527	4.281054	5.9628	0.000996	15.052	36.003	12.764	2.140527	7.526	18.001
2L by 3L	23.122	4.135891	5.5905	0.001393	13.002	33.242	11.561	2.067945	6.501	16.621

Table 2 Effect estimates

Power factor (PF) has effect 1819.137, current (I) 1497.543, and voltage (V) 9046.293 with the same standard errors. Voltage has the greatest effect, but also it has the lowest interaction. The best interaction is between current and power factor 1L by 2L. therefore, voltage is an important factor for itself, whereas power factor and currenthavesignificant interactions. However, according to the P value in the table, power factor, Current, and interaction between power factor and current have significant effect whereas less effect came from Voltage whetherthe main effect or its interactions.

ANOVA;Var.: P; R-sqr=.99998; Adj.99997

3 factors, 1 Blocks, 13 Runs; MS Residual=53.76044

Factor	SS	df	MS	F	P
(1) PF(L)	9707164	1	9707164	180563.3	0.000000
(2) I (L)	6578394	1	6578394	122365.0	0.000000
(3) V(L)	6286	1	6286	116.9	0.000037
1L by 2L	1785451	1	1785451	33211.3	0.000000
1L by 3L	1911	1	1911	35.6	0.000996
2L by 3L	1680	1	1680	31.3	0.001393
Error	323	6	54		
Total SS	20367177	12			

Table 3 ANOVA analysis

In ANOVA table, the best sum of square got from power factor, and the worst sum of square got from the interaction between power factor and voltage. Power factor, current, and interaction between power factor and current gave a significant importance. Voltage and its interactions gave a bad important. So, P value doesn't change from table 2.

Regression.

CoefficientsVar.:P; R-sqr=.99998; Adj:.99997

3 factors, 1 Blocks, 13 Runs; MS Residual=53.76044

DV: Exploited power P

Factor	Regression Coeff.	Std.Err	t(6)	P	-95.% Cnf.Lim	+95.% Cnf.Lim
Mean/interact	2101.58	541.9887	3.8775	0.008194	775.38	3427.78
(1) PF(L)	-2908.15	486.8106	-5.9739	0.000987	-4099.33	-1716.96
(2) I (L)	-476.06	85.3025	-5.5808	0.001405	-684.79	-267.33
(3) V(L)	-3.15	0.8140	-3.8729	0.008238	-5.14	-1.16
1L by 2L	666.82	3.6590	182.2395	0.000000	657.86	675.77
1L by 3L	4.36	0.7318	5.9628	0.000996	2.57	6.15
2L by 3L	0.71	0.1277	5.5905	0.001393	0.40	1.03

Table 4 Regression analysis

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In regression analysis, power factor (PF) has a big negative value, then current (I) andvoltage (V) respectively. The interaction between power factor and current gave a positive value and significant important. Voltage factor has a bad interaction and main effect as well.According to P value, the interaction between current and power factor is the most important in the design according to P value analysis.

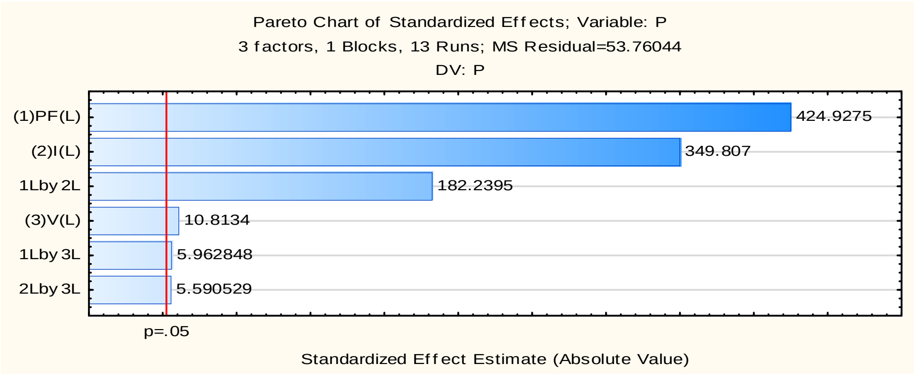

Figure2, Pareto chart of standardized effects variable, exploited power P

From Pareto chart, the most important factor is power factor (PF), current (I), and interaction between power factor and current respectively. Voltage (V) and its interactions gave a low value and less important in the whole parameters design.We did not get any Pareto chart from apparent power response (S) because of the standard error equals to zero.

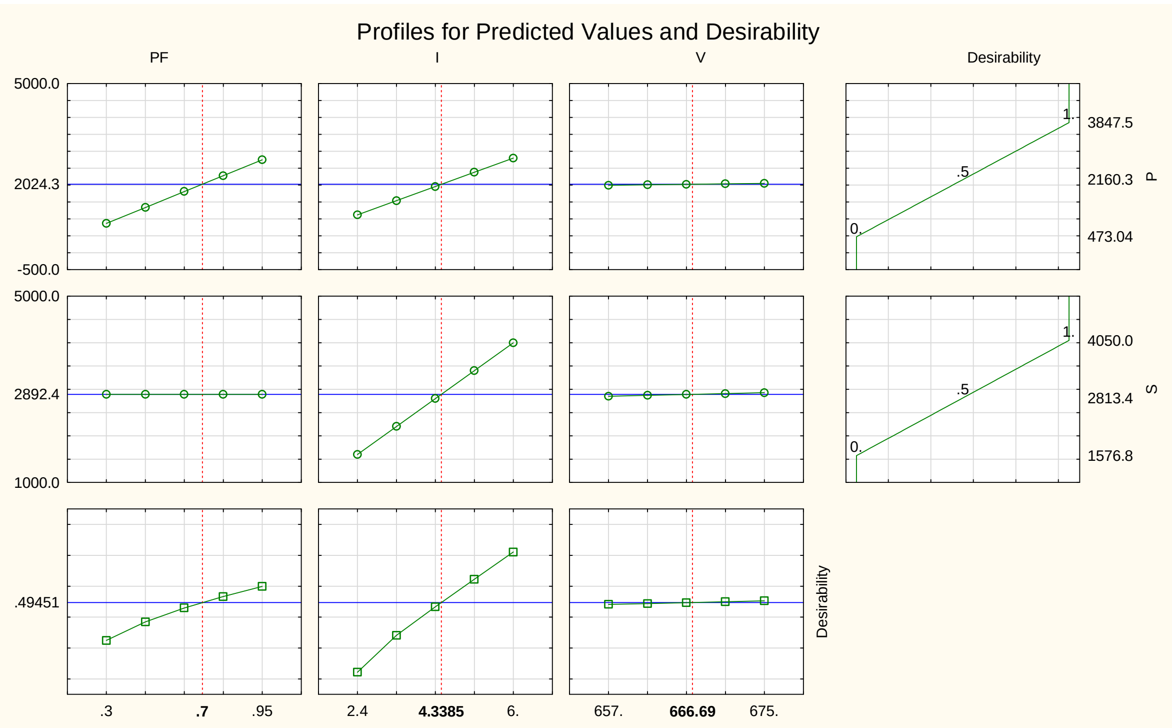

Figure3, main effects for each factor and desirability

The diagramshowed that voltage (V) has a low significant effect in the design, whereas current (I) has strong significant for all stages. Power factor (PF) also has a significant effect, but this effect will be decreased at a range between 1000 and 5000. Desirability for apparent power S is between 1576.3 and 4050 and curve is between 0 and 1, whereas, the desirability for real exploited power P is between 473.04 and 3847.5 and curve is also between 0 and 1.

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Current is very close to desirability and voltagedoes notachieve any desirability, whereas, power factor is very close to desirability in two curves, but also it does not achieve any desirability in the middle curve.
Thus, current and power factor is very important and play a vital role in thedesign. However, thevoltage has a very low important and bad interaction whether with current or power factor. Voltage in estimated effect gave the highest effect, but this effect will be decreased if interacted with any factor.

VIII. CONCLUSION

In this idea, we tried to understand the extracted rules using anexperimental design. in fuzzy logic, we have to get output according to the whole rules, but it is very complicated to understand exact effect for each factor independently without using anexperimental design. We have three inputs and two outputs used to establish rules to predict the optimum outputs. Power factor (PF) and current (I) gave a very important effect and interactions, whereas, voltage (V) gave bad interactions. Experiment design plays a very vital role to diagnosis extracted rules by using electrical equations. ANOVA and regression analysis proved that power factor (PF) and current (I) play a very important role in improving the performance of thethree-phase inductive motor. Results of apparent power have been ignored because its standard error equal to zero and no residuals detected. We considered only exploited power to understand the process because we have standard errors and residual values that gave acomprehensive description to the process. Now, we have to rebuild rules by concentrating on current (I) and power factor (PF) to get more improvement to the performanceof three-phase inductive motors and factory machines as well.

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