PERFORMANCE PREDICTION OF A NEW CONNECTION FOR DUAL VOLTAGE OPERATION OF SINGLE PHASE CAPACITOR RUN MOTOR

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Abstract: *This paper describes the theory and test results of a new connection of Single-Phase Capacitor Run Motor (SPCRM) for dual voltage operation. A program simulating the operation of the new connection gives sufficient results to illustrate its steady state performance. The effects of the operating capacitor on the performance of the new connection are included. Experimental measurements are carried out on both traditional and new connections for comparison and verification of simulating results. The agreement of experimental and computational results approves the modeling of the new connection.*

Key words: *Single phase induction motor, capacitor run motor, dual voltage.*

Nomenclature

r_{1m} main winding resistance;
r_{1a} auxiliary winding resistance;
x_{1m} main winding leakage reactance;
x_{1a} auxiliary winding leakage reactance;
r'_2 rotor resistance referred to main winding;
x'_2 rotor leakage reactance referred to main winding;
x_m magnetizing reactance;
a the effective turns ratio of the auxiliary winding to the main winding;
x_c reactance of capacitor;
n motor speed
I_m main current;
I_a auxiliary current;
I_s supply current;
V_H high supply voltage;

1. Introduction

Single-phase induction motors are widely used because of their cost, reliability and robustness in operation.

A single-phase motor has two unsymmetrical stator windings (main and auxiliary windings), and a squirrel-cage rotor. The main and auxiliary windings are in space quadrature and connected in parallel across the single phase supply. A capacitor is connected in series with the auxiliary winding to produce a sufficient phase shift between the main and auxiliary currents needed for producing an elliptic MMF through the air-gap of the motor. This elliptic MMF produces the starting torque of the motor. Single phase capacitor motors operate either as “capacitor run motor”, where the auxiliary winding is permanently energized, or as “capacitor start motor”, where the auxiliary winding is switched out of circuit by a centrifugal switch nearly at 75% of the motor full load speed, or finally as “capacitor start capacitor run motor”, where the value of the capacitor is large during starting and small during running.

The single phase capacitor run motor (SPCRM) is used for many applications such as heating, ventilating and air conditioning (HVAC) blowers and compressors. The SPCRM has many advantages such as moderated starting torque and good running performance (high out power, high power factor, high efficiency and low supply current) [1].

SPCRM motors for international use are frequently fed by dual voltage such motors capable of operation from high voltage (220/240 V-50 Hz) or low voltage (110/115 V-60 Hz) supplies. These motors are provided with two sets of main windings which can be connected in series for the high voltage operation or in parallel for the low voltage operation. In principle, two sets of auxiliary windings can be provided for similar series and parallel connections. However, it is sufficient practically to fit a single set of the low voltage auxiliary winding. For the low voltage operation, the auxiliary winding is connected directly across the supply via the capacitor. For the high voltage operation, the auxiliary winding is connected in parallel via the capacitor with one set of the main windings (T-connection) i.e. the main windings act as an auto-transformer reducing the high supply voltage to the low voltage required by the auxiliary winding [2].

These types of motors suffer from the following disadvantages:

- The loss the starting torque and humming if the currents pass through each of the main windings sets in opposite directions i.e. the correct connections of the terminals of the main windings sets must be guaranteed.
- The use of different value of the capacitor at low and high voltages operation to obtain high starting and breakdown torques (the capacitance is inversely proportional to the square of the supply voltage, so the capacitance has to be the quadruple at the lower voltage in case of two sets of auxiliary windings)[3].
- The deteriorated characteristics at high voltage in case of T-connection [3].

On the other hand, many researchers [4-7] have studied the steady-state operation of three-phase induction motors when fed from a single-phase supply. Smith proposed a new kind of winding connection method, named Semihex connection, which can make three-phase induction motor operate symmetrically from single-phase supply [4]. The single-phase induction motor with Semihex connection has high efficiency and power factor, but its starting torque is low and the starting circuit is complex [5]. Nabil [6] studied the performance of a three-phase induction motor operating from single-phase supply with a new electronically controlled capacitor using an electronic switch in series with a fixed capacitor to achieve a minimum unbalance of the motor phase voltages at all loading conditions. Xiuhe Wang et al. [7] presented a novel energy efficient single phase induction motor with three series-connected windings and two capacitors. By suitable selection of capacitors, the currents in three windings were approximately symmetrical, and thus, the motor can operate approximately symmetrically from single-phase supply.

This paper presents an analysis for the steady state performance of a new connection of the SPCRM for dual voltage operation. The configuration of the new connection is shown in Fig. 1, where the capacitor is connected in parallel with the auxiliary winding and the parallel combination is connected in series with the main winding across the high voltage supply. This connection could be used for dual voltage operation (220V-110V) as well as for supplying the SPCRM with the line-to-line voltage instead of the line-to-neutral voltage of the same grid in case of missing the neutral point. The paper includes the effects of the operating capacitor on the performance of the new connection. The performance of the new connection has been tested and compared with that of the traditional connection in the laboratory by loading the SPCRM using a dynamometer, and the simulation results obtained were proved experimentally.

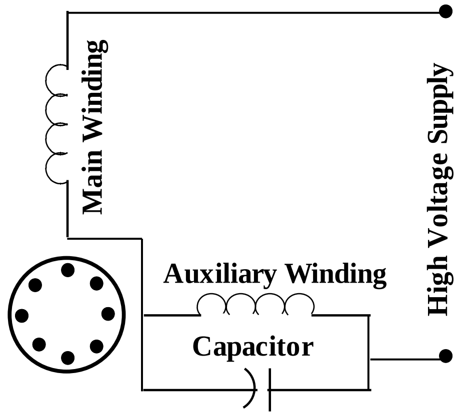

Fig. 1 The new connection of the SPCRM

2. Mathematical Model

Fig. 2 shows the equivalent circuit of the new connection of the SPCRM, based on the double revolving field theory by Morrill [8]. Fig.3 shows the phasor relationship between the main and auxiliary currents during the steady state operation of the new connection. Since the auxiliary current lags the main current then the resulting elliptic MMF of the stator windings will rotate in the clockwise direction according to the windings configuration, and hence the motor will rotate in the same direction. It is known that each stator winding produces a pulsating MMF. This pulsating MMF could be decomposed into two rotating MMFs, having the same amplitude and speed but rotate in opposite directions (forward and backward). Then the SPCRM has four rotating MMFs in its air gap, two forward MMFs and two backward MMFs, consequently each stator winding has four induced voltages: two due to forward and backward MMFs of each winding. According to the winding configuration, where the main winding leads the auxiliary winding in the space by 90° electrically, the induced voltages of the main winding caused by forward MMFs lead that of the auxiliary winding by 90° and consequently the induced voltages of the main winding caused by backward MMFs lag that of the auxiliary winding by 90°. The equations representing the steady state equivalent circuit of the new connection are written in matrix form as follows:

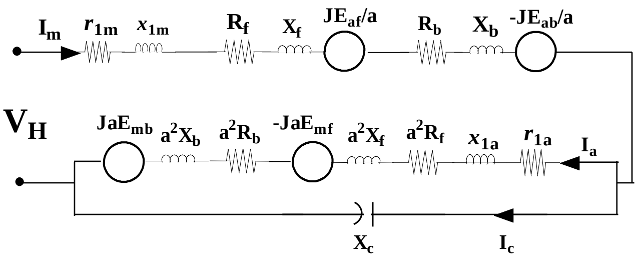

Fig. 2 The equivalent circuit for the new connection of the SPCRM

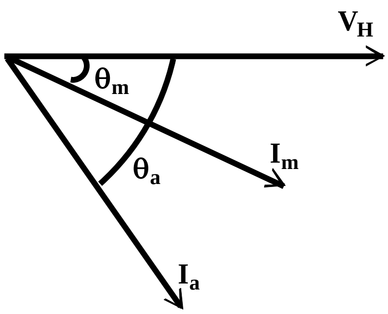

Fig. 3 The phasor relationship of the main and auxiliary currents of the new connection

$$\begin{bmatrix} V_H \\ 0 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} \bar{I}_m \\ \bar{I}_a \end{bmatrix} \quad (1)$$

The solution of these equations under any operating condition gives the main and auxiliary currents. Hence, all the performance characteristics of the motor at this particular load point can be calculated using the following equations:

$$\bar{I}_s = \bar{I}_m \quad (2)$$

$$P_g = (I_m^2 + a^2 I_a^2)(R_f - R_b) + 2aI_m I_a (R_f - R_b)\sin(\theta_m - \theta_a) \quad (3)$$

$$T_d = P_g/\omega_s \quad (4)$$

Where:

$$Z_{11} = Z_{1m} + Z_f + Z_b - JX_c$$
$$Z_{12} = J(a\ Z_f\ \text{-}\ a\ Z_b + X_c)$$
$$Z_{21} = J(a\ Z_b\ \text{-}\ a\ Z_f + X_c)$$
$$Z_{22} = Z_{1a} + a^2(Z_f + Z_b) - JX_c$$

$$\bar{E}_{mf} = \bar{I}_m Z_f$$
$$\bar{E}_{mb} = \bar{I}_m Z_b$$
$$\bar{E}_{af} = \bar{I}_a a^2 Z_f$$
$$\bar{E}_{ab} = \bar{I}_a a^2 Z_b$$
$$Z_{1m} = r_{1m} + Jx_{1m}$$
$$Z_{1a} = r_{1a} + Jx_{1a}$$
$$Z_f = R_f + JX_f = \frac{0.5JX_m(r_2^/ /s + Jx_2^/)}{r_2^/ /s + J(X_m + x_2^/)}$$

$$Z_b = R_b + JX_b = \frac{0.5JX_m(r_2^/ /(2-s) + Jx_2^/)}{r_2^/ /(2-s) + J(X_m + x_2^/)}$$

Z_f ≡ the forward equivalent impedance of the rotor referred to the main winding
Z_b ≡ the backward equivalent impedance of the rotor referred to the main winding
E_{mf}, E_{mb} ≡ the induced voltages in the main winding by its forward and backward MMFs
E_{af}, E_{ab} ≡ the induced voltages in the auxiliary winding by its forward and backward MMFs
aE_{mf}, aE_{mb} ≡ the induced voltages in the auxiliary winding by forward and backward MMFs of the main winding.
E_{af}/a, E_{ab}/a ≡ the induced voltages in the main winding by forward and backward MMFs of the auxiliary winding
P_g ≡ gap power
T_d ≡ developed torque
ω_s ≡ synchronous speed
θ_m ≡ phase angle of the main current
θ_a ≡ phase angle of the auxiliary current

3. Simulation Results

The simulation of the new connection is carried out using a capacitor run single-phase induction motor with the following specifications: 175 W, 220 V, 50 Hz, 1440 rpm, 1.5 A, and a 10 µF capacitor. Table1 gives the experimentally determined parameters of the motor equivalent circuit.

The operation of the new connection is studied by a supply voltage of 380 V-50 Hz to the motor configuration shown in Fig. 1.

Fig. 4 shows the developed torque versus speed curve of the new connection. It is observed that the motor has a sufficient starting torque and approximately 200% over load capacity. Fig. 5 represents the speed- currents curves of the new connection, it is noticeable that the auxiliary winding has a higher current than that of the main winding, but the two currents are smaller than their rated values (1.5 A) within the normal operating speed range. Fig. 6 shows the variations of the power factor and input power versus motor speed. Within the normal operating speed range, it is observed that the motor has approximately a power factor of 0.8. This value can be considered high especially if compared with other types of single phase induction motors.

Table 1 Equivalent circuit parameters of the SPCRM

Parameter	Value
r_{1m}	26 Ω
r_{1a}	24 Ω
x_{1m}	27.375 Ω
x_{1a}	21.053 Ω
r'_2	14.32 Ω
x'_2	27.375 Ω
x_m	283.44 Ω
a	1.0235

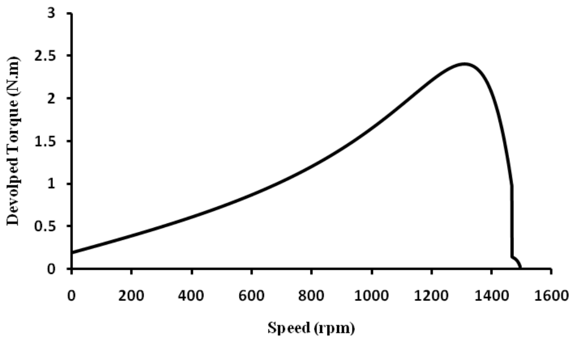

Fig. 4 The developed torque versus speed of the new connection

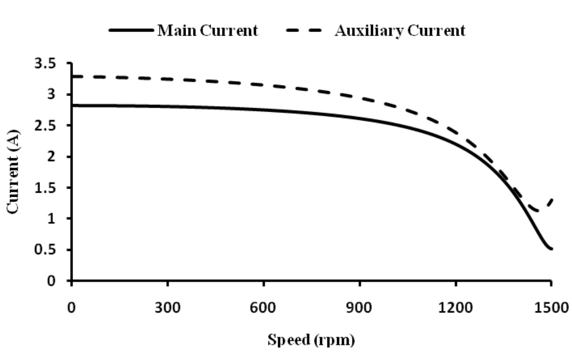

Fig. 5 The speed- currents curves of the new connection

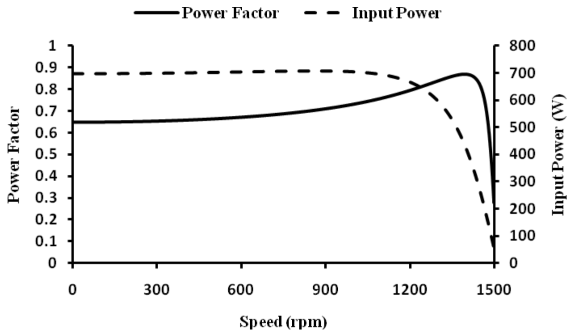

Fig. 6 The variations of the power factor and input power versus the speed

4. Effects of the Operating Capacitor

The steady state performance of the new connection is investigated using different values of the operating capacitor. Fig. 7 shows the simulation results concerning the variation of the developed torque with the capacitor values. It is seen that high values of the capacitor give high values of starting and breakdown torques. Fig. 8 shows the speed power factor curves for different values of the capacitor. It is observed that there is an improvement in the power factor with the increase of the capacitor. The variations of the supply current (main current) with motor speed for different values of the capacitor are shown in Fig. 9. The figure determines the decrease of the main current with the increase of the capacitor. The effect of the capacitor on the auxiliary current is shown in Fig. 10. The figure shows that high of capacitors result in high values of the auxiliary current. The investigation of the new connection with changing the operating capacitor proves that there is a significant improvement in the motor performance at high values of the capacitor except the auxiliary current.

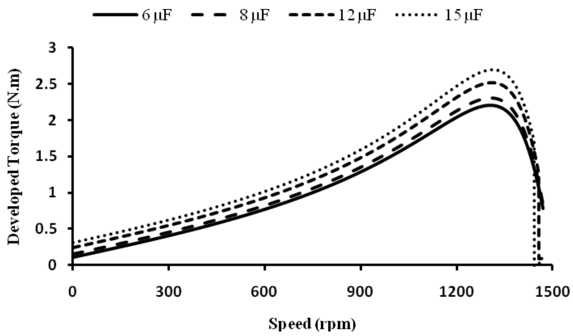

Fig. 7 The developed torque results at different values of the capacitor

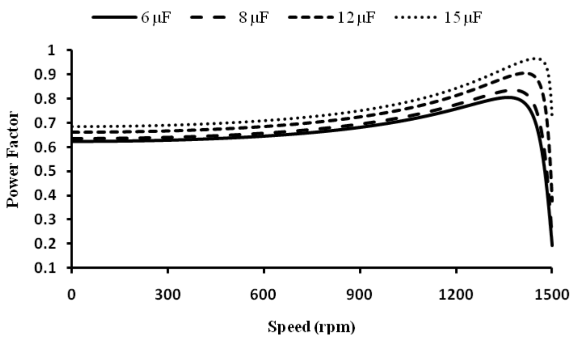

Fig. 8 The speed-power factor curves for different values of the capacitor

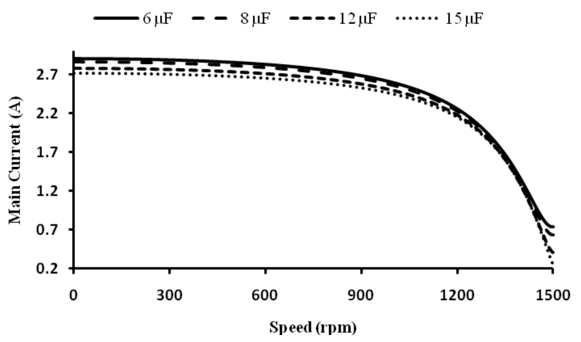

Fig. 9 The supply current versus speed for different values of the capacitor

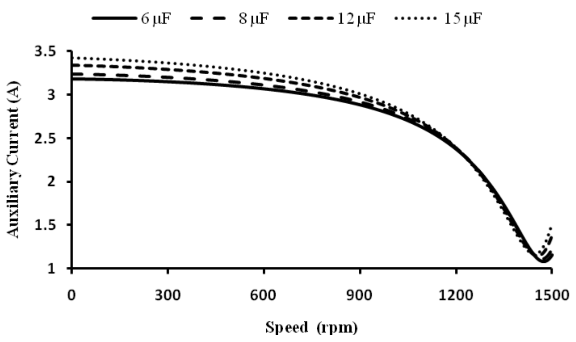

Fig. 10 The auxiliary current versus speed for different values of the capacitor

5. Experimental Results

The new connection is tested and compared with the traditional connection in the laboratory by mechanically coupling the SPCRM to a dynamometer, where the load torque could be electrically controlled. In the traditional connection the auxiliary winding is connected in parallel via the capacitor with the main winding across the supply voltage.

The new connection is investigated by applying a supply voltage of 380 V-50 Hz; while the supply voltage of the traditional connection is 220 V-50 Hz. The operating capacitor is held constant at 10 μF, which is the recommended value for the motor operation under normal conditions. Table 2 illustrates the experimental results of the two connections at the same operating conditions.

The observation of the results in Table 2 yields the following relevant points:

- The motor speed and input power of the new connection are higher than that of the traditional connection.
- The power factor of the traditional connection has always higher values than that of the new connection.
- The supply current of the new connection has low values when compared with those of the traditional connection around the full load conditions.
- The auxiliary current and voltage, of the new connection, have high values, but they are still in the safe range.
- The efficiency of the new connection is slightly lower than that of the traditional connection.

The experimental results presented in this section indicate that the performance of the new connection is satisfactory when compared with the performance of the traditional connection; especially when concerning the motor speed and supply current. It can be observed that the results obtained from simulations fairly agree with the results obtained from experimental tests of the new connection, and the model used is perfectly validated.

6. Conclusions

In this paper, a new connection for operating the SPCRM from dual voltage has been explained theoretically and also has been proved by test. The investigation of the new connection proved that it has a satisfactory performance when compared with the traditional connection. Also it overcomes the disadvantages of the traditional connections for the dual voltage operation of the SPCRM. Using the new connection, it is possible to achieve nearly the same performance as in case of the traditional connection with ordinary stator windings and a same capacitor for both cases.

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Table 2 The experimental results of the two connections

T (N.m)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4
n traditional (rpm)	1490	1479	1463	1456	1435	1415	1394	1360
n new (rpm)	1490	1480	1470	1458	1443	1432	1415	1400
P_{in} traditional (W)	102	131	160	185.5	215	249.5	287	334.5
P_{in} new (W)	122	154	182	216	258	294	338	380
PF traditional	0.917	0.921	0.937	0.968	0.988	0.992	0.992	0.988
PF new	0.394	0.492	0.57	0.644	0.71	0.757	0.796	0.828
Efficiency traditional	0	23.64	38.3	49.32	55.91	59.39	61.04	59.61
Efficiency new	0	20.13	33.8	42.41	46.86	51.0	52.61	54.01
I_s traditional (A)	0.517	0.648	0.784	0.879	1	1.16	1.332	1.554
I_s new (A)	0.817	0.823	0.843	0.882	0.953	1.024	1.116	1.211
I_m traditional (A)	0.937	0.617	0.766	0.793	0.844	0.947	1.1	1.34
I_m new (A)	0.817	0.823	0.843	0.882	0.953	1.024	1.116	1.211
I_a traditional (A)	1.117	1.12	1.09	1.0	0.964	0.949	0.923	0.884
I_a new (A)	1.448	1.4	1.27	1.32	1.3	1.33	1.315	1.24
V_a traditional (V)	251	248.5	244	236	223.5	212.8	201	189
V_a new (V)	280	275	270	265	260	255	250	246
V_c traditional (V)	374.4	368	357	343	326.7	313.5	300.9	287
V_c new (V)	280	275	270	265	260	255	250	246