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# A NEW DESIGN of SIX- PHASE ROTARY CONVERTER ELECTRIC MACHINE

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**Abstract:** The aim of this research is to design a new ac rotary converter machine to convert the ac single phase voltage to six-phase voltages by using multi stages energy conversion machine. The rotary converter is composed from two main stages and is combined into one frame. These two stages are formed from three main electromagnetic components. The first component represents the input stage that enables the energy from single phase to enter and transformed by the second and third components electro-magnetically to produce six-phase voltages which at the output stage. The programs are created using MATLAB in order to calculate the required dimensions of the converter machine and its parameters for magnetic and electrical circuits.

**Keywords:** Renewable fuel, ethanol, numerical simulation, auto ignition, single-step mechanism

## 1. Introduction

Most of the electric power is generated, transmitted and distributed in the form of a.c. current and voltage. An a.c. plant represents a simpler engineering and less economic problems than a d.c. plant. A lot of industrial applications require a d.c. current due to their advantages comparatively to alternating current. Some of these applications can be mentioned briefly [1]:

i. D.C. motors are preferred for their staring and running characteristics, for using in electric tractions and tramways, suburban and underground railways, elevators, etc.
ii. Direct current are suitable for using in electrolytic and electro-chemical processes such as production of aluminum, copper, etc.
iii. It is suitable for using in arc-welding, relays, telephones, time-switches, battery –charging work, etc.

One of the important methods for getting d.c. current is by converting a.c. current to d.c. current. The converted d.c. current from a.c. current is not pure and contains ripples, which it make the quality of d.c. current little and cause interference and distort the small signals in the electronic-communication systems. To enhance the quality of d.c. current, the number of a.c. voltages phases should be increased. Single phase and three phase voltage are commonly used, but not performs the purpose exactly. Therefore, it is necessary to used six phases or more such as nine and twelve to enhance the quality of d.c. current and diminishing undesirable effects due to the ripples.

The classical converting machine [1] has been appeared at the first half of last century. They were manufactured for getting d.c. current by different number of phases in the input side such as single , three, six, nine and twelve phases. These machines are made of double winding layers, the first is for a.c. input voltage and the second are connected for commutation as the like in d.c. motors. In spite of their efficient but they were cost, and needed for a transformer for operation especially in six phases or more in the input side, also they were complicated in their construction and not ease in rewinding when their windings are damaged.

It is worth mentioning that despite of the great development has been done in the field of power electronic since the recent decades of the last century, their usages are limited in low ratings and inside cooled environments otherwise they will be subjected to a great harmful stresses which shorten their working life. In regions which are subjected to hard climate during summer where the average temperature is round 50 to 60 degree centigrade for six to eight hours during mid-day and for three continuous months yearly in the bare areas such as farms. However, electronic converters also have positive advantages; they are silent and can be used in homes, offices and inside closed venues such as for operating small three phase machines like ventilators inside communication mobile racks and the like. Below are some of electronic converter types:

i. Static converter, [2], [3], and [4].
ii. PMW converter, [5], [6] and [7].
iii. Passive element converter [8] and [9].
iv. Matrix converter [10] and [11].

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Solid state single phase to three phase converters still have teething problems. Most static power converters are nonlinear systems which produce undesired harmonics [3] which are generated normally through transforming voltage signal from single to three phases. The output voltage waveform of the converter is not pure sine wave due to the harmonics. The distortion is relevant with increase rating power of devices, also with increase in the current drawn by the load. And the losses due to reverse currents in electronic devices soar proportionally in exponential behavior with raising temperature. In addition, repairing faulted power electronic converts that are composed of electronic devices such as mosfet, triac and diac is not easy and require professional workers as compared to the maintenance and repair rotary converter machines which are much ease.

In this paper, the authors aim to introduce a novel of new design of six phase rotary converter electric machine for converting a.c. single phase voltage, to six-phase voltages.

## 2. Design considerations

The aim of this research is to design a new electric rotary converter machine to convert the single phase ac voltage into other poly-phase voltages. The first stage converts the single phase electric energy input into mechanical energy in the form of rotational movement. This rotational movement rotates the field exciter in the second stage which generates multi-phase voltages on its outer terminals similar to that of a synchronous machine. Good design considerations are required in order to achieve the optimal electrical and mechanical specifications for output power, speed, temperature rise, stresses endurance and conditions of service with economical cost. There are several limitations in designing the electro-mechanical machine which should not be overlooking:

i. Electromagnetic machines use ferro-magnetic materials which are bound to saturate as current increase beyond the limit of flux density of the material.
ii. The electric machine contains one or more type of insulations. The life of the machine is dependent upon the life of these insulations. When the temperature rises above the allowable limit, the life of insulations will be drastically reduced.
iii. The insulations used in the machine is not only subjected to thermal stress but also electrical and mechanical stresses. The type of insulation chosen must have ability to resist the electrical, thermal and mechanical stresses.
iv. The efficiency of the machine must be as high as possible. Otherwise, the energy will be lost in conversion process and defeats the purpose of having the more efficient three phase induction machine to replace the single phase induction machine.
v. Mechanical limitations cannot be ignored. For example, the size of the shaft is limited by the critical speed, the size of the ball bearings are limited by the machine rotor weight, external load, inertia forces due to unbalanced rotor, maximum rotor speed and the length of the air gap is also restricted by mechanical considerations.
vi. The need to maintain a good power factor as closed as possible to unity in order to prevent larger values of current for the same power. Therefore, larger conductor sizes have to be used in order to have power factor near unity.

## 3. Components of machine

The proposed six phase rotary converter machine (6RCM) contains two important stages:

*A*-First stage: It is made up of outer rotor single phase squirrel cage induction motor (ORSPSCIM). Naturally the single phase induction motor is consists of two main parts: stator and rotor. The stationary stator forms the inner fixed part which has concentrated or lapped windings. These windings are divided in to two purposes: main winding, and auxiliary windings. Motor's speed is determined depending on its number of main winding poles (2, 4, 6, etc.). Auxiliary windings are devoted for starting the motor. Many types of single phase squirrel cage induction motors are distinguished and recognized based on connection method of the auxiliary circuits as shown in different types below:

i. Auxiliary circuit is composed of permanent windings connected in parallel with the main windings. These auxiliary windings have a sufficient resistance value to endure the rated current and for making a phase angle between the current passing through the main and auxiliary windings to create staring torque which is proportional to sine the angle trapped between the main and auxiliary currents.
ii. Auxiliary circuit is supported and connected in series with centrifugal switch operating for few seconds to allow the speed to reach 75% of the rated speed. The benefit of centrifugal switch is to produce a high starting torque owing to the proportionality relation between starting torque and current passing through auxiliary circuit. The gross auxiliary winding resistance in this case should be less than the value in the first type to permit passing a large current in them and then producing a high staring torque.
iii. Using operation capacitor in series with auxiliary winding. This circuit is still connected in parallel with main winding. In this configuration is experienced an improvement in both starting and operating merits.
iv. Using two capacitors, the first is permanent connected in series with auxiliary windings and its propose for getting batter operation, while the second is temporary capacitor is allocated for getting a good staring. The second capacitor is connected in series with centrifugal or relay switch and both are engaged in parallel across the terminal of first capacitor. This type of single phase induction motor has a proper

performance and used in places necessitate a high starting torque when begin loaded.

In the new design of the rotary converter, the first stage which is the outer rotor single phase squirrel cage induction motor mentioned previous should be used for getting a high starting torque and a positive rotation. It is operating with single phase voltage is surrounded by outer squirrel cage rotor. Generally as in any design, it must be designed based on the demanded specifications of the suggested rotary converter rating, speed, frequency, rated input and output voltages. These will be utilized to calculate the engineering dimensions of machine.

As referred in Fig. 1, and Fig. 2. The first stage is designed for operating on the input single phase voltages.

Fig.1. Component 1, Stator of first stage rotary converter.

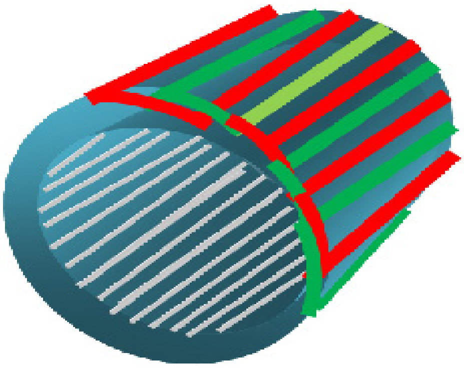

Fig.2. Component 2, Dual functions, the inside surface as armature of single phase I.M. and in same time the outside surface as a stator of synchronism R.C.

Either 110V or 220 V, at a frequency of 50 or 60 Hz respectively. The stator may have tapered slots for small ratings or rectangular slots for high ratings by taking different sizes for stator slots depending on the number of conductors per slot. The starting and running windings in the stator windings are always preferred to be wounded in a concentric manner. The 2/3 stator slots are allocated for the main or running windings while the reminder 1/3, starting windings will be inserted in. The common winding types used are concentric, progressive, and skein windings. In small single phase motors, it may be desirable to reduce the harmonics further by having parallel sided teeth or vice versa. The slot's house is sized with the number conductors per slot, i.e., by grading different number of conductors in slots thereby giving mmf which nearly approaches a sine wave.

Second stage in the proposed rotary converter has a main role in producing six-phase voltages similar to a synchronous generator. For simple review, it consists of stator (named Armature) shown in Fig.3. The armature may be comprised of three, six, nine or twelve phases which is made up of a block of laminations mounted in a cast iron or die cast aluminum alloy frame. The armature has tapered slots for small rating machines or it may have rectangular slots in high rating machines. Armature windings are always preferred to be wounded in lap or progressive coils, which give a good value of winding factor, reaching more than ninety percent. The rotor in synchronous generates is different in its design than others in induction machines. It consists of numerous a pair of salient or non-salient poles, which can be done of permanent magnetic poles in small rating synchronous generators or wounded poles in high rating machines. The rotor are run by an external prime –mover. In this research the rotor of the second stage will be taken its rotational movement from the first stage as the role of prime-mover.

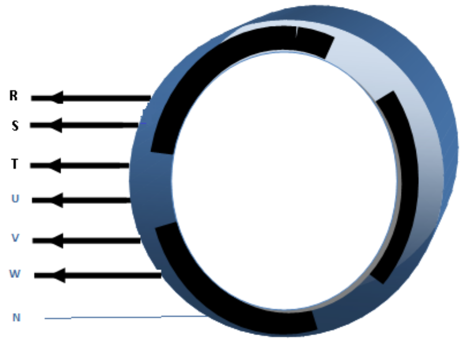


Fig.3. Component 3, Armature of R.C. six phase generation.

## 4. Design methodology

The design procedure adopted for the new six rotary converter machines can be summarized by the flow chart shown in Fig. 4, which consists of the following steps:

a. The required or demanded specifications of the machine must first be evaluated.
b. Design of first stage (outer rotor single phase squirrel cage induction motor).
  i. Determination of engineering dimensions.
  ii. Stator design and its details.
  iii. Rotor design.
  iv. Losses and Efficiency calculations.

c. Second Stage:
  i. Determination of engineering dimensions.

ii. Armature design and its details.
iii. Rotor Design.
iv. Losses and Efficiency calculations.

In the process of any machine design [12, 13, 14, 15], there are headlines or general rules should be followed by all the designers. These rules are not constrained in one or two fields, it comprises the all. As mentioned previously, it has been explained that there are three fields in the machine design under consideration: Electro-magnetic design, thermal design and mechanical design as shown in Fig.4. Each field also discriminated to many subdivided such as the thermal design has a main role the thickness of insulation used and design of the type of cooling either forced or natural, by gas or liquid,…etc. and in the same time, these parameters are related with power rating of machine. In the thirty recent years, there were at least three significant ways followed in pursuit of design electric machines. Another method and formulas due to efforts many of researchers in the world contribute currently in modification and improving the main ways [15], and [16]. The proposed completed six- phase rotary converter machine is shown in Fig.5.

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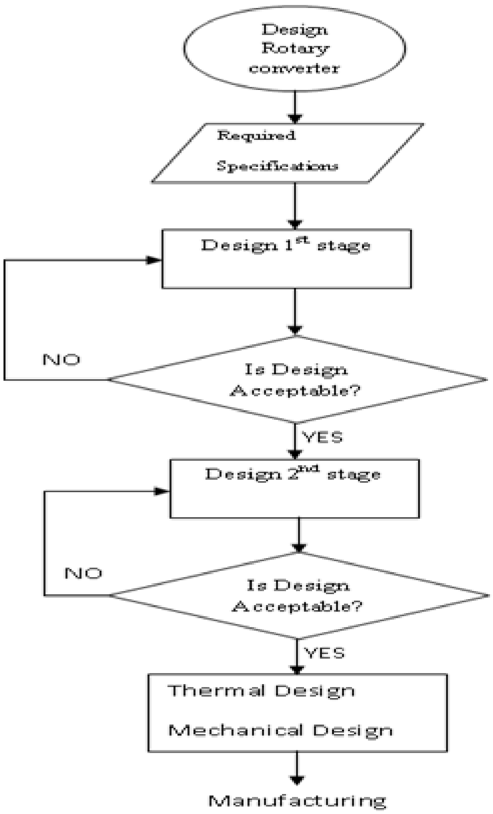


Fig.4. General Flow chart layout explains sequential steps of design rotary converter electric machine.

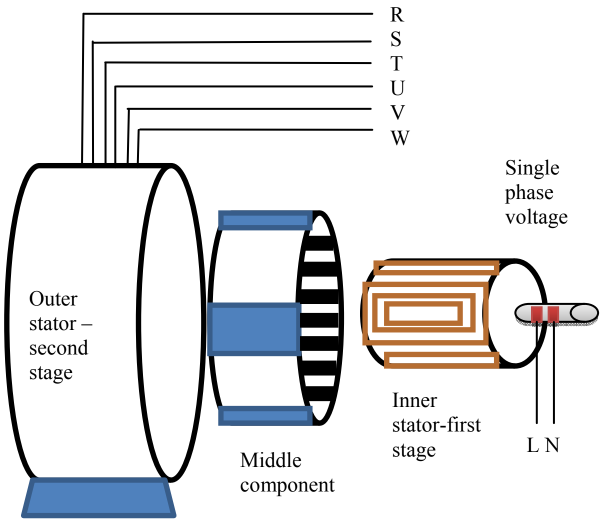


Fig.5. General Shape of six – phase rotary converter machine.

## 5. Data analysis

Correlating design equations and calculating the expected results are fulfilled with following successive steps. These steps are allocated and specialized based on the required designed part or component. After completing the mathematical steps and getting reasonable designed results, the next step is programming the mathematical model by using MATLAB. The following equations show part of the design trend.

*A-First stage*

i. The first step starts with using general output equation is given by (1).

$$Q = C_o D^2 L n \quad (1)$$

Where $Q$ is KVA power rating, $C_o$ is the output coefficient. $D$ is bore diameter, $L$ is stator length, and $n$ is synchronous speed in r.p.s.

ii. Then calculate the number of turns per phase, $T_{ph}$ can be calculated using (2).

$$T_{ph} = Es/(4.44 f \phi_m K_{ws}) \quad (2)$$

iii. Calculations consists stator slot pitch $y_{ss}$ as shown using (3). The number of conductors per one slot $Z_s$, number of total conductors in all stator slots is $Z_{ss}$, and number of stator slots $S_s$ can be determined using (4).

$$y_{ss} = \pi D / S_s \quad (3)$$

$$Z_s = Z_{ss} / S_s \quad (4)$$

iv. Two important flux densities must be checked under their conditions *(I) stator teeth flux density* $B_{ts} \leq 1.7$ *T*, and *(II) stator core flux density.* $1.2 \leq B_{cs} \leq 1.7T$.

Number of poles $P$, net iron length $L_i$, $\phi_m$ is average flux density, $d_{cr}$ is depth of stator core.

$$B_{ts} = \phi_m /[(S_s/P)\times W_{ts}\times L_i] \quad (5)$$

$$d_{cr}= (\phi_m /2)/(B_{cr}\times L_i) \quad (6)$$

*B-Second Stage*

As referred in Fig.2, and Fig.3. The second stage is being surrounded round the first stage. i.e. the rotor exciter of second stage will be stuck and perform a circular ring around the outer rotor squirrel cage. Of course, the exciter rotor needs a rotational moving to set a revolving flux which is necessarily to establish induced voltages on the terminal of the terminal phase armature windings. Some of calculations should be implemented for determining the required parameters and the main dimensions as shown below.

i. Number of Poles $P$ and synchronous speed $n_s$ is given by (7).

$$P = \frac{2f}{n_s} \quad (7)$$

ii. The output power of the generator $Q$ is given by (8).

$$Q = C_o D^2 L n_s \quad (8)$$

By Rearranging (8), is obtained from which the greater length and diameter can be determined.

$$D^2 L = \frac{Q}{C_o n_s} = \frac{P_{in}\times\eta}{C_o \cos\phi\, n_s} \quad (9)$$

,where the product of machine input powers $P_{in}$ proposed on its shaft and the efficiency of machine $\eta$ gives the real output power of the machine $P_o$.
The output co-efficient $C_o$ is given by (10).

$$C_o = 11 K_{ws} B_{av}\, ac \times 10^{-3} \quad (10)$$

The normal values for specific electric loading $ac$ for all machines are within the *Design Condition III*: $5000 \le ac \le 60000\, A/mm^2$ as stated in [12, 13] assuming that the machine is air cooled. The usual values for average flux density $B_{av}$ in the air gap for the three phase synchronous generator with salient poles should be within the limits as dictated by *Design Condition IV*: $0.35 \le B_{av} \le 0.6T$ .

## 6. Conclusion

The new rotary converter is a single piece construction; hence it is built from iron or rolled steel and placed inside enclosure. It is possible to deduce some important benefits and merits of the new rotary converter:

i. It is self-starting.
ii. It can be used for generating three, six, or twelve phase.
iii. The output voltages have a high efficiency of balanced multi-phase operation.
iv. By adding rectifier equipment at its output terminals, it is easily getting D.C. voltage.
v. It is easy to maintain and rewinding.
vi. It is capable of endurance high ambient temperatures.
vii. Its overall noise strength is expected similar to normal single phase induction motor.
viii. Its weight and size within the acceptable range.

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