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ISSN: 2348-2079

APR-2015

International Journal of Intellectual Advancements and Research in Engineering Computations

EQUATION BASED SELECTIVE HARMONICS ELIMINATION USING MATRIX CONVERTER

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ABSTRACT

Selective Harmonic Elimination (SHE) is often utilized in both two-level inverters and multilevel inverters to reduce the switching frequency and the Total Harmonic Distortion. For both two level and multilevel inverters, most SHE studies are based on solving multiple variable high order nonlinear equations. This dissertation addresses the further developed harmonics injection and equal area criteria based four-equation method to realize Selective Harmonic Elimination for two-level inverters and multilevel inverters with unbalanced dc sources. Compared with existing methods, the proposed method does not involve complex equation groups and is much easier to be utilized in the case of large number of switching angles or multiple switching angles per voltage level in multilevel inverters. For harmonics compensation for active power filters, the proposed method is modified for selective harmonics generation based on distributed energy resources. By using advanced instantaneous power theory, the four-equation based method can be used as a comprehensive and universal solution for reliable and efficient power delivery in smart grids. Simulation is carried out in MATLAB/ SIMULINK software and the results of matrix converter based selective harmonic elimination are presented.

INTRODUCTION

The implementation of high frequency Pulse Width Modulation (PWM), based two-level inverters is limited due to voltage levels, and current ratings of switching devices, switching losses, and electromagnetic interferences caused by high dv/dt. Thus, to overcome these limitations, multilevel inverters have been proposed as a promising solution. In the next steps, different circuit topologies, control algorithms, and the applications for multilevel inverters are described. In multilevel converters, a different source of energy, such as battery, renewable energy sources, and dc voltage by capacitor banks can be utilized together for desired ac voltage at a higher power rating. In this case, the voltage and power rating of power electronic switches will be determined by the input dc sources For high power applications, the advantages and disadvantages of multilevel inverters compared with two level inverters using high frequency Pulse Width Modulation (PWM) methods. The performance of multilevel inverter is compared based on computation of switching angle using conventional the Runge Kutta or ruler’s method. A significant improvement in harmonic profile is achieved in the Runge Kutta (Four Equation method) based approach.

EXISTING SYSTEM

Distributed energy resources (DERs) are expected to provide ancillary functions including reactive power generation and harmonics compensation. Meanwhile, multilevel inverters and two-level converters with Optimal Pulse Width Modulation (OPWM) will be commonly used for DERs at high power levels.The challenge is to realize harmonic compensation with limited switching angles. This paper presents an online solution to realize the selective harmonics compensation (SHC), and power generation with DERs. For harmonics compensation, the selective harmonic components in the load current are detected.

Then, the harmonic voltages are provided with DERs to cancel out these detected components. Since the power converter is requested to realize

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harmonics filtering and power generation, limitations on harmonics compensation at the given power are discussed. Power hardware-in-the-loop-based online verifications are shown at the end of the paper. Methods for both switching angle calculation and harmonics detection are proposed. The tradeoff between harmonic compensation and power generation is discussed based on proposed switching calculation method.

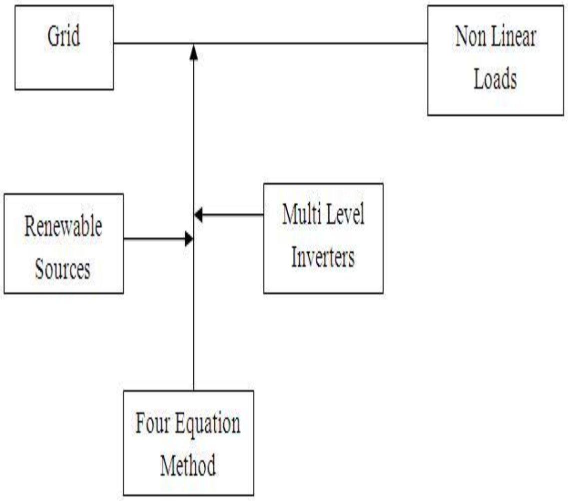
BLOCK DIAGRAM

DERs are being considered as promising generation sources to meet the continuously increasing energy demand and to improve reliability of electric power systems. To increase the system efficiency and maximize the return of the investments on DERs, ancillary functions such as harmonics and power compensations have also been considered. This means that the distributed resources can be utilized as APF while supplying active/reactive power to the load and the grid. In this case, DERs will be controlled to:

1) generate desired active and reactive power for the loads and the grid

2) Compensate selective harmonic currents caused by nonlinear loads.

The system topology is shown in Fig.2.1. It should be noted that this grid-tie inverter will often work with high modulation indices.



Block diagram of existing system

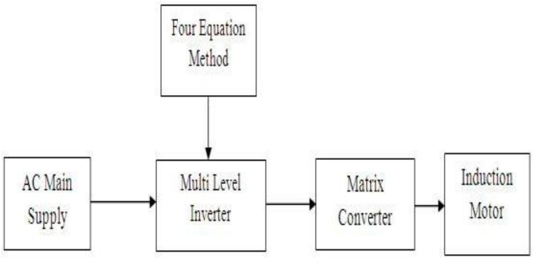
PROPOSED SYSTEM

Selective Harmonic Elimination (SHE) is often utilized in both two-level inverters and multilevel inverters to reduce the switching frequency and the Total Harmonic Distortion.

For both two level and multilevel inverters, most SHE studies are based on solving multiple variable high order nonlinear equations. The main objective of selective harmonic elimination pulse width modulation strategy is eliminating low - order harmonics by solving nonlinear equations.

- The proposed method does not involve complex equation groups and is much easier to be utilized in the case of large number of switching angles or multiple switching angles per voltage level in multilevel inverters.
- For a multilevel inverter, switching angles at fundamental frequency are obtained by solving the selective harmonic elimination equations in such a way that the fundamental voltage is obtained as desired and certain lower order harmonics are eliminated. As these equations are nonlinear transcendental in nature, there may exist simple, multiple or even no solutions for a particular modulation index.
- Selected harmonics elimination based methods have been proposed for both two-level and multilevel inverters. This section is focusing on the SHE based methods for multilevel inverters. Ideally, in the multilevel inverters, for every voltage level, there could be multiple switching angles.
- The number of eliminated harmonics is decided by the number of voltage steps and number of switching angles in each voltage step. However, because of the complexity of the problem, most studies proposed so far are for one switching angle per one voltage level.
- This also means that the switching frequency in these methods can be as low as the fundamental frequency. The main objective of selective harmonic elimination pulse width modulation strategy is eliminating low - order harmonics by solving nonlinear equations.

BLOCK DIAGRAM



Block Diagram for Proposed System

BLOCK DIAGRAM DESCRIPTION

The basic block diagram for this project is shown in Fig 4.1 which shows the four equation method of selective harmonic distortion of multilevel inverter. In these applications, the frequency of the Pulse Width Modulation (PWM) is often limited by switching losses and electromagnetic interferences caused by high dv/dt.

Thus, to overcome these problems, Selective Harmonic Elimination (SHE) is often utilized in both two-level inverters and multilevel inverters to reduce the switching frequency and the Total Harmonic Distortion. For both two level and multilevel inverters, most SHE studies are based on solving multiple variable high order nonlinear equations. Furthermore, for multilevel inverters, SHE has been often studied based on the assumption of balanced dc levels and single switching per level.

This dissertation addresses the further developed harmonics injection and equal area criteria based four-equation method to realize Selective Harmonic Elimination for two-level inverters and multilevel inverters with unbalanced dc sources. Compared with existing methods, the proposed method does not involve complex equation groups and is much easier to be utilized in the case of large number of switching angles or multiple switching angles per voltage level in multilevel inverters.

Selected harmonics elimination based methods have been proposed for both two-level and multilevel inverters. This section is focusing on the SHE based methods for multilevel inverters. Ideally, in the multilevel inverters, for every voltage level, there could be multiple switching angles. The number of eliminated harmonics is decided by the number of voltage steps and number of switching angles in each voltage step. However, because of the complexity of the problem, most studies proposed so far are for one switching angle per one voltage level.

This also means that the switching frequency in these methods can be as low as the fundamental frequency. The Advantages of this system is ideally by solving these polynomial equations, the selected harmonic components can be eliminated very precisely. Though advanced methods such as symmetric polynomials, resultant theory combined method and generic algorithm-based methods can greatly reduce the calculation time, these methods are difficult to be adopted by field engineers, because of the need for pre-understanding of advanced control and mathematic theories.

EXPLANATION OF PROPOSED SYSTEM

The aim of the proposed system is to eliminate the selective harmonics using matrix converter with the four equation method. This method tries to solve the harmonics elimination problems from a totally different angle of approach. No high-order multi-variable polynomial equations would be involved in this method. To better illustrate the method, two well-known examples of switching angle calculation and harmonics compensation are first introduced. For a simple equation group based on Fourier’s series, Runge Kutta iteration can be used to achieve numerical solutions.

For the Runge Kutta based approach, the initial values are very crucial to the final results. As matter of fact, due to the discontinuous input currents, the matrix converter behaves as a source of current harmonics, which are injected back into the AC mains. Since these current harmonics result in voltage distortions that affect the overall operation of the AC system, they have to be reduced.

The principal method of reducing the harmonics generated by static converters is provided by input filter using reactive storage elements. The problem of the input filter design for a matrix converter has been addressed and looking at the literature, different configurations have been proposed for the matrix converter input filter. Such differences are a consequence of different design criteria, or at least differently weighted, different switching frequencies and different modulation strategies. However, with other approaches, no harmonics elimination can be realized.

In addition to these requirements, a set of considerations related to cost, voltage attenuation, system efficiency and filter parameter variation have to be made for an optimized input filter design. The input filter has to reduce the input current and output voltage total harmonic distortion below given values. In order to achieve this result, the resonant frequency of the filter has to be positioned accordingly to the converter switching frequency and its PWM pattern.

When the input current harmonic spectrum generated by the converter is known, the filter resonance frequency is positioned where no unwanted harmonic components exist, which is usually the frequency range comprised between the fundamental and the switching frequency. In practice, due to the presence of imperfections and asymmetry in gating signals as well as implementation inaccuracies, some unwanted or uncharacteristic harmonics with small amplitude might exist in this region.

If no damping is provided, these unwanted harmonics can be amplified by the filter to unacceptable level. On the other hand, a highly damped filter could not meet the harmonics attenuation requirements. A phase displacement of the filter input current with respect to the line-to-neutral voltage proportional to the filter capacitance value is always present. Thus, in order to maintain high input power factor the capacitor size has to be minimized. This typically translates into an upper limit for filter capacitor value.

As far as the matrix converter is concerned, a high displacement angle of the input line current due to the input filter capacitance component might be compensated by the matrix converter, setting as reference for the input current a lagging displacement angle. But in this way the maximum voltage transfer ratio for the converter would be significantly reduced. Therefore, even for the matrix converter, the upper limit of the input filter capacitance is set by the minimum acceptable AC mains power factor. In general, the filter output impedance should be as low as possible when compared to the converter input impedance. In the power distribution system, Active Power Filters (APFs) are used to eliminate voltage/current harmonics in utility power lines.

To eliminate harmonics that already existing in the utility power lines, APF will inject new harmonic voltages or currents to the lines. The injected harmonics would have the same amplitudes but opposite phase angles of the aimed harmonics. Thus, the harmonics in the utility line could be cancelled. The key idea of APF is count-harmonics injection. By combining equal area criteria and the idea of harmonics injection together, a new method to find optimum switching angles can be found.

MATRIX CONVERTER

The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub-harmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors.

It requires more semiconductor devices than a conventional AC-AC indirect power frequency converter, since no monolithic bi-directional switches exist and consequently discrete unidirectional devices, variously arranged, have to be used for each bi-directional switch. Finally, it is particularly sensitive to the disturbances of the input voltage system. The matrix converter consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The circuit scheme is shown in Fig.4.1.

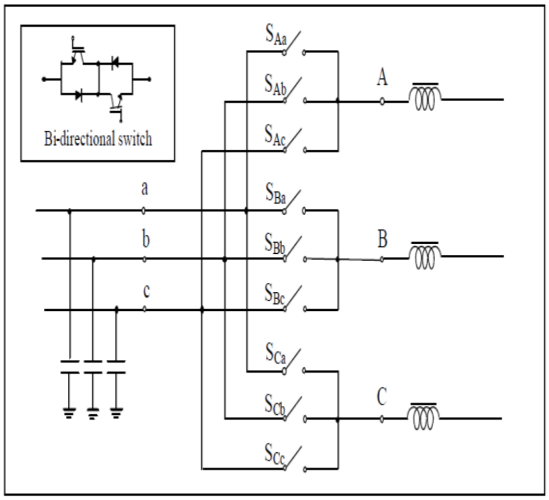


Fig.4.1 Circuit diagram of three phase to three phase matrix converter.

a, b, c are at the input terminals. A, B, C are at the output terminals.

The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current- fed system, like an induction motor might be. The capacitive filter on the voltage- fed side and the inductive filter on the current- fed side represented in the scheme of Fig.4.1 are intrinsically necessary. Their size is inversely proportional to the matrix converter switching frequency.

It is worth noting that due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter: a current-fed system at the input and a voltage- fed system at the output. With nine bi-directional switches the matrix converter can theoretically assume 512 different switching states combinations. But not all of them can be usefully employed.

Regardless to the control method used, the choice of the matrix converter switching states combinations (from now on simply matrix converter configurations) to be used must comply with two basic rules. Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. A qualitative analysis of some performance parameters is carried out. Some numerical results based on a simplified model of a matrix converter system.

FOUR EQUATION METHOD

Equation 1: to use the harmonics elimination method for multilevel inverters is achieved by four equation method. Unlike other methods published before, the proposed method does not need to solve high order polynomials. Only four simple equations and minimum calculation time are needed.

The four-equation-based method is developed to solve the following three problems: SHE-based optimal switching angle calculations for two level inverters, SHE for multilevel inverter with unbalanced dc sources and multiple switching angles per level in multilevel inverters at low-modulation indices, which is equivalent to high modulation indices in inverters.

Solving high-order nonlinear equations is no longer needed, thus, advanced algorithms are also no longer required. In the traditional methods, the number of equations grows with the number of switching angles in nonlinear way. Thus, it is very difficult to calculate the switching angles when the total number of the switching angles is high. Conversely, in the four-equation method, the four basic equations are used repeatedly; the total number of equations grows linearly with the number of switching angles. Only four equations are needed to be calculated in this four equation method.

equal area criteria, δ_k, the junction point of the modulation waveform and voltage level *k* must first be found. For a modulation waveform with harmonics contents, it is difficult to find a symbolic solution for δ_k.

$$\delta_k = arctg\left(\frac{k \cdot V_{dc} + h_5 \sin(5\delta_k) \cdots + h_m \sin(m\delta_k)}{V_F \cos(\delta_k)}\right)$$

(4.1)

Equation 2: after δ_k s is found, the switching angle, θ_k, can easily be calculated from:

$$\theta_k = k\delta_k - (k-1)\delta_{k-1} + V_F(\cos(\delta_k) - \cos(\delta_{k-1}) - \frac{h_5}{5}(\cos(5\delta_k) - \cos(5\delta_{k-1})))\cdots - \frac{h_m}{m}(\cos(m\delta_k) - \cos(m\delta_{k-1})) \quad (4.2)$$

where m is the order of the harmonic.

Equation 3: with a new set of θ_k , the new harmonics contents can be found as:

$$h_m = \sum_{k=1,2,\cdots N}^{N} \frac{2}{(2k-1)\pi}(\cos(m\theta_k) - \cos(m(\pi - \theta_k))) \quad (4.3)$$

Equation 4: to perform iterations of step 2)-4) mentioned in this section, the modulation waveform would have a general expression as:

$$V_F \sin(\omega t) - h_{5\_s} \sin(5\omega t) \cdots - h_{m\_s} \sin(m\omega t)$$

(4.4)

Where h_{m_s} is the sum of the h_m found after each iteration:

$$h_{m\_s} = \sum_{i=1,2,3\cdots iter}^{iter} h_m$$

(4.5)

The modulation index for staircase waveform in a multilevel inverter is defined as:

$$MI = \frac{V_F}{\frac{4}{\pi} N \cdot V_{dc}}$$

(4.6)

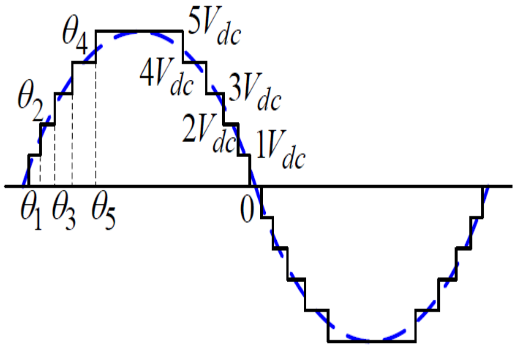


Fig 4.3. The four-equation based method

The advantages of four equations based method compared with a polynomial equations solution can be summarized as follows:

1. The complexity of the four equations for different number of switching angles will be the same. Therefore, the switching angles can be calculated easily without using advanced mathematical methods or numerical solution such as used in polynomial methods.
2. For a higher number of switching angles in multilevel inverters, the number of first ordered equations that should be solved in polynomial methods, will be increased nonlinearly. However, this increase is linear for the four-equation based method, resulting in fewer numbers of first ordered equations. Therefore, the four-equation based method can be implemented faster with an easy control algorithm. Then, this method is a very good candidate for an online SHE in multilevel inverter.

Most of the proposed methods use the group of polynomial equations for SHE based on Fourier's series. However, when the number of dc levels increase, the number of polynomial equations, the number of variables, and the order of the equations will all increase accordingly. Thus, finding solutions to these equations would become extremely difficult and often involve advanced mathematical algorithms, which make the calculation easy to reach capability limits of existing computer algebraic software tools. In a four-equation based method, equal area criteria and harmonics injection are utilized for SHE in multilevel inverters. Then, compared with other methods that normally use the polynomial equations, solving high order nonlinear equations is no longer needed.

THE CHARACTERISTICS OF A BASIC FOUR EQUATIONS METHOD

Initially, to prove the concept, this method has been used to calculate the switching angles for the case shown in Figure 4.4. In the calculations, five harmonics are chosen for elimination. After approximately 100 times of iterations, the values of 5th, 7th, 11th, 13th, and 17th harmonics drop under p.u, which means these harmonics are effectively eliminated. The number of eliminated harmonics is five and equal to the number of switching angles. Please note that with other methods proposed so far, to eliminate five harmonics with a total of five switching angles, the result in a fundamental component would be far from the desired value.

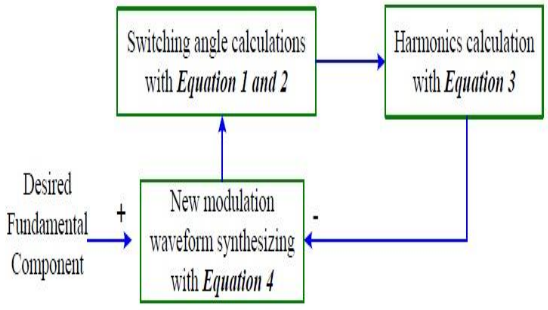


Fig 4.4 Different switching angles in multilevel inverters

With the proposed method, because the equal area criteria are used all the time, the resulted fundamental component is still close to the desired value. For a desktop computer with a 2.8 GHz CPU, the calculation time of one modulation index is less than 1 second.

$$MI = \frac{V_F}{\frac{4}{\pi} \times 5 \times V_{dc}}$$

(4.7)

Where V_F is the peak value of the fundamental component.

MAIN PROBLEM IN THE BASIC FOUR EQUATIONS METHOD

The main problem identified from this process is the amplitude difference between the desired and resulted fundamental component in the output voltage. With the direct implementation of the proposed method, the fundamental voltage of the staircase waveform often diverts from the desired value. The reason is that, for most cases, it is difficult to find a good solution for the switching angle for the top dc level to satisfy the equal area criteria. For the last switching angles based on the top cross section point, the magnitude of the reference voltage is more than the summation of dc levels. Therefore, the area of reference voltage above the last dc level cannot be compensated effectively. Thus, the magnitude of fundamental voltage that is generated by multilevel inverters is less than that of the reference voltage.

When the selected harmonics are injected to the reference waveform, multiple cross section points can be detected on a quarter for each dc level. Then, multiple solutions of δ_k for one dc level were originally expected to be another major problem of the four-equation based method. However, studies show that the equal area criteria can automatically settle on the middle cross point, which is the best selection of e_{ke}.

RUNGE–KUTTA METHODS

In numerical analysis, the Runge–Kutta methods are an important family of implicit and explicit iterative methods, which are used in temporal discretization for the approximation of solutions of ordinary differential equations. One member of the family of Runge–Kutta methods is often referred to as "RK4", "classical Runge–Kutta method" or simply as "The Runge–Kutta method".

Let an initial value problem be specified as follows.

$$\dot{y} = f(t, y), \quad y(t_0) = y_0.$$

(4.8)

Here, *y* is an unknown function (scalar or vector) of time *t* which we would like to approximate; the function *f* and the data are given.

Now pick a step-size *h*>0 and define

$$y_{n+1} = y_n + \tfrac{h}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right)$$
$$t_{n+1} = t_n + h$$

(4.9)

For $n = 0, 1, 2, 3, \ldots$, using

$$k_1 = f(t_n, y_n),$$
$$k_2 = f(t_n + \tfrac{h}{2}, y_n + \tfrac{1}{2}k_1 h),$$
$$k_3 = f(t_n + \tfrac{h}{2}, y_n + \tfrac{1}{2}k_2 h),$$
$$k_4 = f(t_n + h, y_n + k_3 h).$$

(4.10)

Here y_{n+1} is the RK4 approximation of $y(t_{n+1})$, and the next value (y_{n+1}) is determined by the present value (y_n) plus the weighted average of four increments, where each increment is the product of the size of the interval, *h*, and an estimated slope specified by function *f* on the right-hand side of the differential equation.

- k_1 is the increment based on the slope at the beginning of the interval, using $\dot{y}$, (Euler's method) ;
- k_2 is the increment based on the slope at the midpoint of the interval, using $\dot{y} + \frac{h}{2}k_1$;
- k_3 is again the increment based on the slope at the midpoint, but now using $\dot{y} + \frac{h}{2}k_2$;
- k_4 is the increment based on the slope at the end of the interval, using $\dot{y} + hk_3$.

In averaging the four increments, greater weight is given to the increments at the midpoint. The weights are chosen such that if f is independent of y, so that the differential equation is equivalent to a simple integral, then RK4 is Simpson's rule. The RK4 method is a fourth-order method, meaning that the local truncation error is on the order of $O(h^5)$, while the total accumulated error is order $O(h^4)$.

A general formula for a Runge–Kutta method in the fourth-order as follows:

(4.11)

$$y_{n+1} = y_n + \tfrac{h}{6}\left[k_1 + (4-\lambda)\,k_2 + \lambda k_3 + k_4\right]$$
$$t_{n+1} = t_n + h$$

$$k_1 = f(t_n, y_n),$$
$$k_2 = f(t_n + \tfrac{h}{2}, y_n + \tfrac{h}{2}k_1),$$
$$k_3 = f(t_n + \tfrac{h}{2}, y_n + \left(\tfrac{1}{2} - \tfrac{1}{\lambda}\right)k_1 h + \tfrac{1}{\lambda}k_2 h),$$
$$k_4 = f(t_n + h, y_n + \left(1 - \tfrac{\lambda}{2}\right)k_2 h + \tfrac{\lambda}{2}k_3 h).$$

For $n = 0, 1, 2, 3, \ldots$, using

, (4.12)

Where, λ is a free parameter. Choosing $\lambda = 2$, this is the classical fourth-order Runge-Kutta method. With $\lambda = 1, 3, 4, 5$, this formula produces other fourth-order Runge-Kutta methods.

In general a Runge–Kutta method of order s can be written as:

$$y_{t+h} = y_t + h \cdot \sum_{i=1}^{s} a_i k_i + \mathcal{O}(h^{s+1}),$$

(4.13)

Where:

$$k_i = f\left(y_t + h \cdot \sum_{j=1}^{s} \beta_{ij} k_j, t_n + \alpha_i h\right)$$

are increments obtained evaluating the derivatives of y_t at the i-th order.

ASYNCHRONOUS INDUCTION MOTOR

An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and VFD applications.

PRINCIPLES OF OPERATION

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance.

The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings.

The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors.

The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors. For rotor currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque.

The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion. The stator of an induction motor consists of poles carrying supply current to induce a magnetic field that penetrates the rotor.

To optimize the distribution of the magnetic field, the windings are distributed in slots around the stator, with the magnetic field having the same number of north and south poles. Induction motors are most commonly run on single-phase or three-phase power, but two-phase motors exist; in theory, induction motors can have any number of phases. Many single-phase motors having two windings can be viewed as two-phase motors, since a capacitor is used to generate a second power phase 90° from the single-phase supply and feeds it to the second motor winding. Single-phase motors require some mechanism to produce a rotating field on startup.

Cage induction motor rotor's conductor bars are typically skewed to reduce noise. According to Faraday’s law an EMF induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an EMF is induced in the rotor copper bar and due to this EMF a current flows through the rotor conductor.

Thus from the working principle of three phase induction motor it may observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds equals, there would be no such relative velocity, so no EMF induction in the rotor & no current would be flowing, and therefore no torque would be generated. Consequently the rotor cannot reach at the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.

CONCLUSION AND FUTURE WORK

Selective Harmonic Elimination (SHE) is often utilized in both two-level inverters and multilevel inverters to reduce the switching frequency and the Total Harmonic Distortion. For both two level and multilevel inverters, most SHE studies are based on solving multiple variable high order nonlinear equations. Furthermore, for multilevel inverters, SHE has been often studied based on the assumption of balanced dc levels and single switching per level.

This dissertation addresses the further developed harmonics injection and equal area criteria based four-equation method to realize Selective Harmonic Elimination for two-level inverters and multilevel inverters with unbalanced dc sources. The proposed method is applied for optimal PWM when the number of dc level limited for the inverters. For harmonics compensation for active power filters, the proposed method is modified for selective harmonics generation based on distributed energy resources.

Different real- time simulation and experimental results verify the simplicity and accuracy of the proposed method for these approaches. By using advanced instantaneous power theory, the four-equation based method can be used as a comprehensive and universal solution for reliable and efficient power delivery in smart grids. Simulation is carried out in MATLAB/ SIMULINK software and the results of matrix converter based selective harmonic elimination are presented

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