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Pulse Width Modulated AC Voltage Controller Filter Design by Optimization Technique

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Abstract The AC voltage controller plays a vital role in many of the industries. In this paper the multiple pulse width modulated AC voltage controllers is designed for analyzing the different loads. The performance of AC voltage controller is analyzed with and without filter. The performance parameters are output voltage and total harmonic distortion. The performance analysis is done for pulse width modulated AC voltage controller with resistive load and combination of resistive and inductive load. The design of passive filter components is obtained using particle swarm bacterial foraging optimization technique. The effect of filter requirements is analyzed using the Matlab software.

Keywords— Filter component, optimization technique, total harmonic distortion, AC Voltage controller

I. INTRODUCTION

The AC Voltage controller plays important role in industries for the application on controlling high speed fan and pump control systems[8]. The cost and economy of the controller is cheap compared to other different methods of speed control. In the literature different topologies is described like TRIAC control, phase angle control and single pulse width modulation techniques [15]. TRIAC control is the simplest and economic voltage regulators but the harmonic in the output voltage is more. The phase angle control is best suited for different load conditions for energy saving mechanisms but the distortion in the waveform is more at larger triggering angle. Single pulse width modulation is utilized for ac voltage controllers.

From the literature it is understood that phase control is better compared to single pulse width modulation for energy saving strategy [11]. The multiple pulse width modulation and extinction angle control shows better performance compared to other conventional controllers [9]. The passive filter and active filters plays vital role in making the waveform smooth and maintain the total harmonic distortion within the limits. The design of passive filter is utmost importance for enhancing the quality of ac voltage controllers.

The novel method of harmonic elimination method compared to fixed duty cycle method for removing lower order harmonics [1]. This result gives good indication of using new technique for eliminating lower order harmonics. This requires further investigation of eliminating other harmonics. This paper gives insight view of using optimal capacitor for AC chopper was done through simulations [2]. This can be done by hardware for further enhancement in studies. The new concept of series resonant conversion for AC chopper was studied. Finally a simple passive filter is used to filter the harmonics [3]. The total harmonic distortion is less that 5% from hardware realization. This paper analyses conventional method of ac voltage controller and this paper uses symmetrically controlled technique to reduce the harmonics. The main drawback is use of force commutation which causes major effect on output voltage [4]. This paper focuses on design of input and output filters of ac voltage controllers. The major drawback of this method is duty cycle affects the power factor and hence optimal capacitor design is required [5].

The main objective of this paper is to analyse the steady state equivalent circuit pulse width modulation of ac voltage controller for resistive and resistive-inductive load. Initially the performance is analysed without passive filter components for multiple pulse width modulation of ac voltage controller for both resistive and resistive-inductive load. The transfer function for ac voltage controller with resistive and resistive-inductive load is derived. From this the power factor is calculated and taken as objective function for the optimization algorithm. The optimization is performed for suitable values of filter inductance and capacitance to minimize the objective function. The performance parameters for the ac chopper are total harmonic distortion and pure sinusoidal of ac output voltage.

II. ANALYSIS OF PWM AC VOLTAGE CONTROLLER

The pulse width modulation of AC voltage controller plays vital role in industries [6]. The power circuit consists of main IGBT with four diodes and for freewheeling action has supplementary IGBT with four diodes are formulated as power circuit and the diagram is shown in figure1. During positive half cycle the main IGBT will conduct through diodes D1 and D2 and pass through load and return back to supply. The freewheeling action takes place when main device is off and supplementary device is on. During negative half cycle current passes through load, diodes D3 , main device and diode D4 and

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return back to supply. From this operation it is implied that pulse generation is designed such that main and supplementary IGBT will not conduct simultaneously.

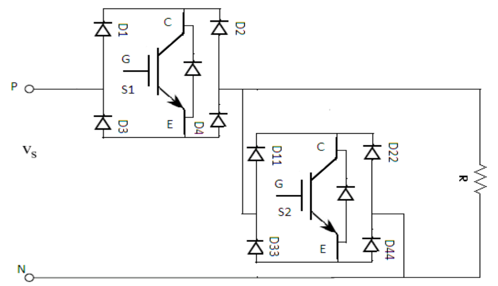

Fig 1. PWM AC voltage controller with R Load

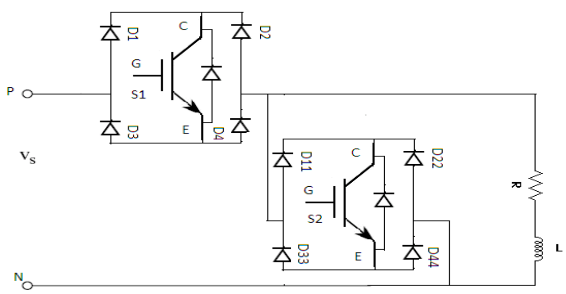

Fig 2. PWM AC voltage controller with RL Load

Under steady state conditions the output voltage of AC voltage controller is given by [2]

$$V_O = D * V_1 \tag{1}$$

The steady state equivalent circuit is given by

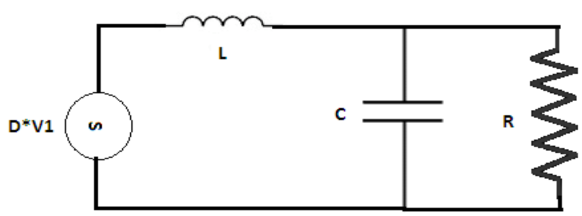

Fig 3. Steady State Equivalent circuit

The filter inductance design can be obtained by the formula

$$L = \frac{V_m T(1-D)}{I_{ripple}} \tag{2}$$

The capacitance value should be greater than the designed value.

$$C = \frac{V_m T^2 (1-D)}{8 * L * V_{ripple}} \tag{3}$$

The main purpose of passive filter in AC voltage controller gives distortion free output. The filter inductor should be optimum value such that the harmonics in the output voltage is less and the larger value of inductance causes power dissipation in the filter circuit is more. The value of capacitance decreases the angle between the voltage and current gives near unity power factor. In the equivalent circuit the impedance is taken as resistive load R_a. D is the duty ratio, L and C are filter inductance and capacitance respectively. The transfer function for the above equivalent circuit with resistive load is a second order function.

$$V_O(s) = \frac{D\, V_1(s)}{s^2 LC + s\frac{L}{R_a} + 1} \tag{4}$$

The final transfer function is given as

$$\frac{V_O(s)}{V_1(s)} = \frac{D * R_a}{s^2 LCR_a + sL + R_a} \tag{5}$$

The angle θ is obtained from the equation (5) shown below

$$\theta = \tan^{-1}\left(\frac{\omega^2 LCR_a + \omega^2 L}{R_a}\right) \tag{6}$$

The transfer function[2] for the above equivalent circuit with resistive and inductive load is obtained as

$$\frac{V_O(s)}{V_1(s)} = \frac{D(R_a + sL_a)}{s^2 LC(R_a + sL) + sL + R_a + sL} \tag{7}$$

The angle θ is obtained from the equation (8) shown below

$$\theta = \tan^{-1}\left(\frac{\omega L_a}{R_a}\right) - \tan^{-1}\left(\frac{\omega^3 LCL_a + \omega^2 LCR_a + \omega(L + L_a)}{R_a}\right) \tag{8}$$

III. PARTICLE SWARM BACTERIA FORAGING OPTIMIZATION TECHNIQUE

The conventional algorithm like dynamic programming, ziegler-nichlos method and genetic algorithm solves the non-linear mathematical problems. The dynamic programming method has tedious steps and time consuming. The output converges at longer time. In ziegler-nichlos is the basic method of obtaining the proportional integral and derivative gains of a particular control system. This method has larger settling time and peak overshoot, hence unsuitable for accurate control system problems. This paved the way for optimization of solving non-linear equations. The first and foremost is the concept of genetic algorithm. From this many new concepts have arrived like swarm intelligence, ant colony and many other new concepts for solving the non-linear problems [7].

The particle swarm optimization is the behavior of colony of swarm of ants and flock of birds. The main objective of this optimization is finding the food in least possible time and path taken to reach the final point. Each particle is assumed to have position and velocity. In the search space the swarm of birds will move in random direction. When it finds the best position it will remember and communicate to other birds for the food. The position and velocities are adjusted depending on the food locations.

$$V_1^{m+1} = w_v * V_1^m + C_1 * rand1(LP_1 - CP_1^m) + C_2 * rand2(GP_1 - CP_1^m) \quad (9)$$

Where V is the velocity of particle, C_1, C_2 are constants, LP_1 is local position, CP_1 is current position, GP_1 is global position and w_v acceleration factor. If the position of all the particles are obtained then it is converged. Otherwise the second iteration will start by starting from local best position and global best position.

The bacteria foraging optimization basically evolves the concept of E.coli bacterium. The concept of E.coli is it searches for food and the bacteria grows, while when it is near with noxious substances it will retard [14]. There are three basic operations in bacterial foraging optimization method they are chemotaxis, reproduction and elimination and dispersal. The chemotactic step play important role for improving or retarding the strength of bacteria. When the environment is good and all the nutrients will be adding for bacteria and the size will improve. When the environment is not suitable for growth then it will retard and disappear.

The swimming operation allows in moving with other bacteria possibly in clockwise direction. The tumbling operation will be used when there is any change in operation. Normally it rotates in anti-clockwise direction especially when the noxious environment occurs. The second step of reproduction operation the bacteria with good nutrients will increase in size and asexually split into two parts.

The chemotactic step is given below.

$$M(i,j,k,l) = M(i,j,k,l) + R(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \quad (10)$$

Where R(i) is step length, O is number of variables used in optimization and $d_{attractant}$, $W_{attractant}$, $h_{repellant}$, $W_{repellant}$ are the different coefficients in the optimization algorithm. F(M,O(j, k, l) is the objective function need to be minimized, are the different coefficients are chosen properly for the optimized value of the passive filter design.

$$F(M,O(j,k,l)) = \sum_{i=1}^{S} F(M,M^i(j,k,l))$$

$$= \sum_{i=1}^{S} -d_{attractant}\exp(-W_{attractant})\sum_{m=1}^{P}(M_m - M_m^i)^2$$

$$+\sum_{i=1}^{S} h_{repellant}\exp(-W_{repellant})\sum_{m=1}^{P}(M_m - M_m^i)^2 \quad (11)$$

In the final step is the elimination and dispersal in this the good healthy bacteria will survive for the next iteration and unhealthy bacteria will be eliminated. The good food source location will be remembered and for the next iteration this process will continue till the convergence result is obtained. In this paper the objective function is given as

Objective function F = $\dfrac{1}{power\ \ factor}$

Subjected to

$F_{Min} <= F <= F_{Max}$

Where F (L, C) and the corresponding range of values indicate the minimum and maximum value of passive filter components.

4.RESULTS AND DISCUSSION

4.1Resistive Load

The variation of duty cycle with fundamental AC voltage is tabulated for resistive load of multiple pulse width modulated AC voltage controller. The tabulated values are shown from without filter. The load resistance used is 50 ohms.

Table I : PWM AC Voltage controller Resistive load without filter

S.No	Duty Cycle	Fundamental output voltage in volts
1	0.1	5.68
2	0.2	34.27
3	0.3	48.76
4	0.4	64.81
5	0.5	84.77
6	0.6	93.01
7	0.7	128.2
8	0.8	140.4
9	0.9	167.6

Table II :PWM AC Voltage controller Resistive load with filter

S.No	Duty Cycle	Fundamental output voltage in volts
1	0.1	27.7
2	0.2	57
3	0.3	86.7
4	0.4	116.3
5	0.5	150.9
6	0.6	181
7	0.7	212
8	0.8	242
9	0.9	250

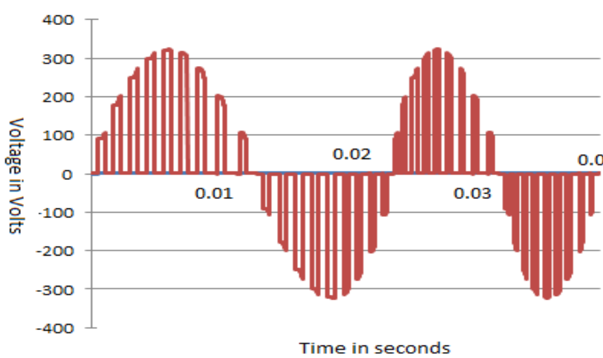

Fig 4 Output Voltage waveform for resistive load without filter

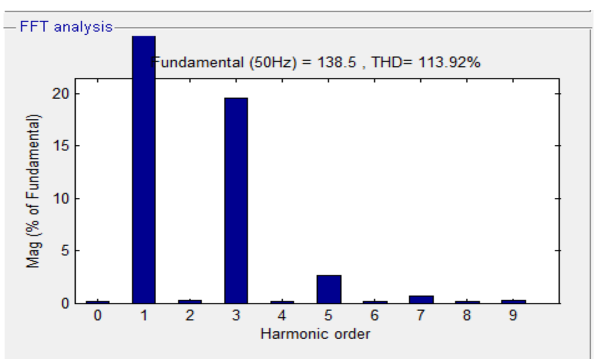

Fig 5 Total Harmonic distortion for resistive load without filter

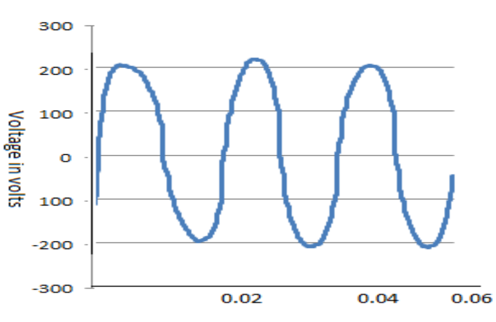

Fig 6 Output Voltage waveform for resistive load with filter

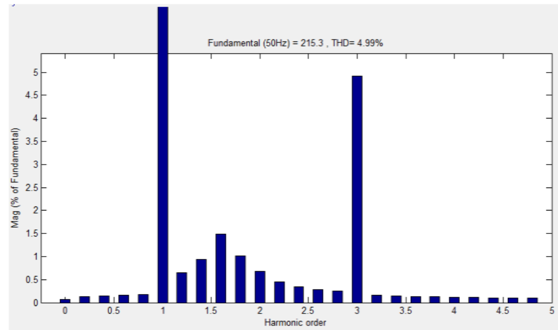

Fig 6 Total Harmonic distortion for resistive load with filter

4.2 Resistive and Inductive Load

The variation of duty cycle with fundamental AC voltage is tabulated for resistive-inductive load of multiple pulse width modulated AC voltage controller. The tabulated values are shown from without filter. The load resistance used is 50 ohms and load inductance used is 10 milli Henry.

Table III.

PWM AC Voltage controller Resistive-Inductive load without filter

S.No	Duty Cycle	Fundamental output voltage
1	0.1	7.92
2	0.2	19.26
3	0.3	54.21
4	0.4	73.01
5	0.5	91.76
6	0.6	110.5
7	0.7	129.3
8	0.8	148
9	0.9	166.6

Table IV :PWM AC Voltage controller Resistive-Inductive load with filter

S.No	Duty Cycle	Fundamental output voltage in volts
1	0.1	29
2	0.2	72
3	0.3	110
4	0.4	147
5	0.5	185.6
6	0.6	223
7	0.7	261
8	0.8	298
9	0.9	335

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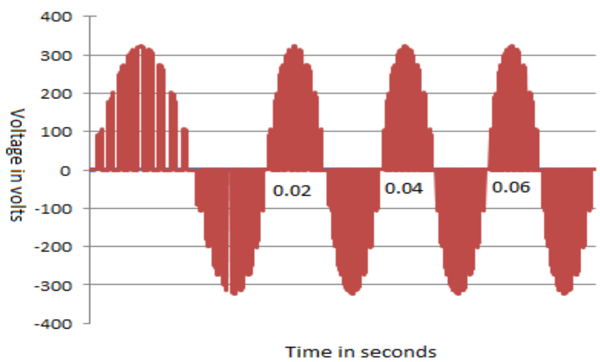

Fig 7 Output Voltage waveform for resistive and inductive load without filter

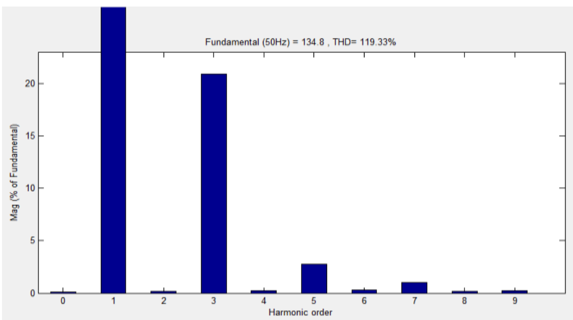

Fig 8 Total Harmonic distortion for resistive and inductive load without filter

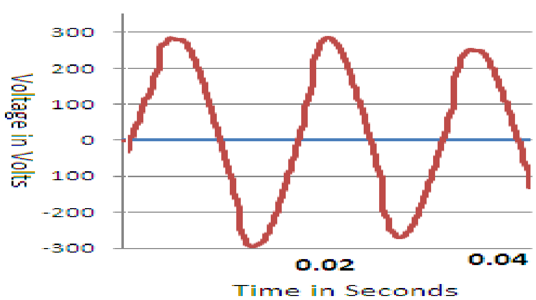

Fig 9 Output Voltage waveform for resistive and inductive load with filter

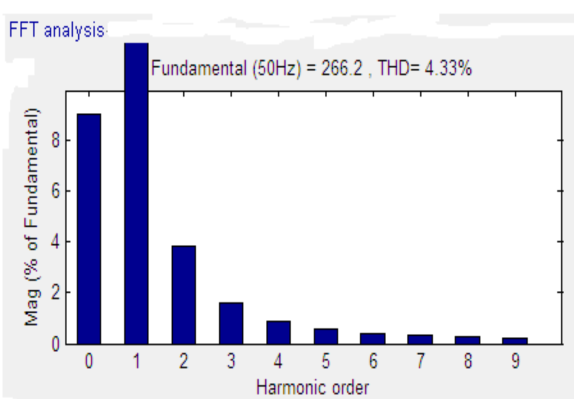

Fig 10 Total Harmonic distortion for resistive and inductive load with filter

A computer code has been done using Matlab m file programming. The design data are fed in to the program along with the subject to constraints is mentioned. The objective function is calculated for different iterations and it should have minimum value. The corresponding values of passive filter components are obtained from the program. The estimated values are simulated using MATLAB simulink environment to get the necessary sinusoidal output voltage and permissible limits of total harmonic distortion.

It is understood that by the application of filter the output voltage waveform becomes pure sinusoidal. The total harmonic distortion is high value without filter and it is with in permissible limits of 5percentage for the resistive load. The passive filter components are obtained from the optimization algorithm as L = 20 milli Henry and capacitor value is 200 microfarad. The passive filter is also applied for resistive and inductive load. The output voltage is not purely sinusoidal because of multiple pulse width modulation. The percentage of harmonics is of high value. By using the filters the value of total harmonic distortion is reduced. The values of filter components are L = 50 milli Henry ; and C = 300 microfarad.

5.CONCLUSION

The performance analysis of multiple pulse width modulation fed ac voltage controller feeding resistive and resistive-inductive load is obtained with and without filter. This is done using analytical methods combined with optimization algorithm and simulation using MATLAB simulink. Some concluding interpretations from the exploration are as follows. The output voltage has improved significantly by using passive filter for both loads at any duty ratio of the ac voltage controller. In resistive load the output voltage is more than input voltage at duty ratio of 0.9 is due to the effect of capacitance value. The total harmonic distortion for the resistive load without filter is 113% while by incorporating the filter in the circuit the total harmonic distortion is 4.99% within the permissible limit of International electrical and electronics engineering standard. The output voltage waveform of pulse width modulation is not proper sine wave. After filtering operations the waveform is considered to purely sinusoidal. For resistive inductive load the waveform is sinusoidal. The waveform of current wave form is shifted by some angle due to the fact that load is inductive nature. This can averted by closed control of current makes the waveform sinusoidal.

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