Design of Parameters of Buck Converter Integrated to a Hybrid DC Micro Grid using Genetic Algorithm

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Abstract:
Buck converter transforms constant DC voltage into a variable DC voltage and gives out average output voltage less than the input voltage. Applications of Buck converter starts from few watts range such as consumer electronics like mobile charger, laptop charger to kilo watts range in electrical engineering like renewable energy sources, electric vehicles and DC micro grids. Buck converter considered for the study in this paper integrates wind power generation to a hybrid DC micro grid. When the wind generator output varies, input to Buck converter also varies. The inductance and capacitance values of the Buck converter are varied under the condition of variable input voltage; to maintain the average output voltage constant with reduced transients such as peak voltage, percentage ripple and settling time. To find the optimal values of inductance and capacitance under varying input voltage condition Genetic Algorithm is used. The proposed method is verified by simulating Buck converter and Genetic Algorithm in MATLAB/Simulink environment.

Keywords: Buck converter, Capacitance, Inductance, Genetic Algorithm

I. INTRODUCTION

Buck converter is a step down DC- DC transformer, it reduces the output voltage level to a desired value less than the input voltage without change in power, and therefore the output current of the Buck converter is always greater than the input current. The power rating of Buck converter varies from few Watts to KWs depending on the field of application. And some of the field of application of Buck converter are electronic gadgets like mobile and laptop charger, Electric vehicles, Renewable energy sources and DC micro grids. A Buck converter circuit consists of a main switch (a controllable power electronic device) such as power MOSFET or IGBT, auxiliary switch diode, energy storage elements like inductor and capacitor. A Buck converter operates in two modes, they are continuous current mode (CCM) and discontinuous current mode (DCM) and these two modes of operation depends on inductor value of the Buck converter circuit. The output voltage of the Buck converter depends on the ON time of the main switch, so the average output voltage can be maintained at the desired level by adjusting the duty ratio. Generally all converters are provided with at least one controller to maintain the output voltage constant. There are number of control techniques developed such as Sliding mode control [2], Model predictive control [1],[5], FPGA based control[4] to control the output voltage. Genetic Algorithm is used to obtain optimal values for the gain constants of PID controller [3] to control output voltage of Buck converter. But the performance of the controllers also depend on the parameters of the plant.

The Buck converter considered in this paper, is used to integrate wind generated power to a hybrid DC micro grid of voltage rating 110 volts. As the power output of wind turbine depends on the wind speed and pitch angle, with variation of these parameters power output of turbine varies. In turn the output of the generator coupled to wind turbine also varies giving the power at varying voltage and this varying output voltage of generator is rectified and fed as input to the Buck converter.

Generally inductance and capacitance values are designed for constant value of input voltage, if the variation in the input voltage is around the designed value, then the Buck converter gives the acceptable performance. If there is large variation in the input voltage from the designed value then the performance of the Buck converter may be poor, like it may enter into DCM, increase in peak output voltage, increase in the ripple beyond the acceptable range. So to avoid such undesired performance an algorithm is proposed to find the optimal values for the inductance and capacitance based on Genetic Algorithm [11] to suit the variable input voltage.

Generally optimization techniques are used to obtain the optimal solution by finding the maximum or minimum value of the objective function. Genetic Algorithm is a random search method used to obtain optimal solution for a nonlinear equation and the solution is a numerical constant. But in this case the function to be optimized is transfer function of Buck converter which is a differential equation. And the solution is voltage and current waveforms which are functions of time. Therefore instead of optimizing the objective function, Buck converter with a PI controller is simulated with different pair of inductance and capacitance values for a particular value of input voltage. Noted down the peak values, percentage ripple and settling time for output voltage and inductor current for different pair of inductance and capacitance value starting from minimum to maximum values. This forms database for that particular input voltage, similarly database can be formed by simulating Buck converter for different input voltages with different set of inductance and capacitance values and stored. When the input voltage to the Buck converter varies, Genetic Algorithm finds the optimal values of the inductor and capacitor based on the specified limits of the required parameters. The paper is arranged in the following order, section I Introduction, section II Buck Converter, section III Genetic Algorithm, section IV Problem Formulation, section V Implementation, section VI Results and section VII Conclusion.

II. BUCK CONVERTER

A Buck converter converts constant DC input voltage into a variable DC voltage, and the average output voltage of the Buck converter is always less than the input voltage. This is achieved by switching operation of the main switch MOSFET Q. Figure .1 represents the circuit diagram of a Buck Converter. When the MOSFET is ‘ON’ (by applying gate pulse) current flows from source V_i through MOSFET Q, inductor L and through parallel connected capacitor and load resistor R and the diode is reverse biased acts as open circuit .During this period the output voltage is equal to voltage across capacitor V_c and current through inductor i_L increases from i_{Lmin} to i_{Lmax}. When the MOSFET is ‘OFF’ and acts as open circuit so the load is disconnected from the supply. But the diode is forward biased and acts as freewheeling diode provides

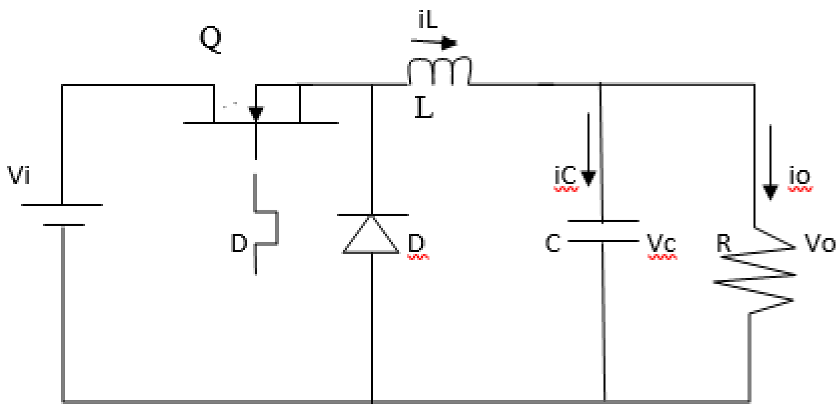

Figure.1 Buck Converter circuit

energy discharging path for the inductor and hence current through the inductor decreases from i_{Lmax} to i_{Lmin}. If the minimum current i_{Lmax} is less than zero then Buck converter enters into discontinuous current mode operation [9] [10]. Therefore selection of inductor value plays a vital role in the operation of Buck converter. The equations for calculating inductance and capacitance values are as follows; inductance,

$$L = \frac{V_o * (1-D)}{f_s * \Delta I_o} \quad (1)$$

Where

V_o – output voltage

D – duty ratio

$$D = \frac{V_o}{V_i} \quad (2)$$

Vi – input voltage

f_s - switching frequency

ΔI_o – ripple in the output current

capacitance,

$$C = \frac{\Delta I_o}{8 * f_s * \Delta V_o} \quad (3)$$

ΔV_o – ripple in the output voltage.

III. GENETIC ALGORITHM

Genetic algorithm is a subset of Evolutionary computation inspired by theory of natural evolution proposed by Charles Darwin. This algorithm resembles natural selection process in which the appropriate individuals are nominated for reproduction to produce offspring for next generation. This process starts with a set of population, appropriate individuals are selected from this population to produce the off springs. These off springs have the inheritance of parent's characteristics and are part of the next generation. This process of finding the appropriate individuals keeps on iterating and at the end, appropriate individuals are obtained. This concept can be applied to a search problem to obtain best results. While applying this Genetic algorithm to optimization problem to obtain the best solution, phases have to be followed are;

Fitness function, Initialization of population, Selection, Reproduction, Crossover and Mutation.

The fitness function is a function of decision variables (individuals).The Genetic algorithm attempts to optimize the fitness function defined by the user. The fitness function examines and evaluates the 'fitness' of each potential solution. Initial population formed is a group of individuals. The fitness function is estimated using the members of the initial population. Based on the fitness of the individuals, the individuals which have higher fitness will be selected for next generation. These individuals then take part in reproduction to generate off springs. Then the off springs will be mutated randomly. This process will be repeated based on the accuracy requirement of the user [8].

In binary coded Genetic Algorithm the individuals are the binary strings [6],[7],[8].But in continuous Genetic Algorithm the individuals are real numbers. Estimation of the fitness function and selection process of chromosomes for reproduction of off springs remain the same as binary coded GA, but the crossover and mutation operations are carried out with minor modification.

The function f(x, y) to be optimized is a function of two decision variables x and y. Therefore the number of parameters Npar=2, and the chromosomes are of the form[x,y], size of the population is Np ,crossover percentage is Cp, mutation percentage is Mp,number of parents or off springs Nc and number of mutants is Nm. Therefore initial population is vectors of x and y with size Np and this population is randomly generated real numbers with minimum and maximum limits.

For the next generation to maintain the population size half of the fitting population from the existing population is retained through selection and other half of the population is obtained through selection and crossover. The probability of all the individuals for selection will be calculated, and individuals with higher value of probability will be selected as parents for production of next generation.

Mating of a pair creates two off springs, so Npar/2 parent chromosomes are required to produce appropriate number of off springs to obtain the desired population. In continuous Genetic Algorithm the chromosomes are real numbers so the crossover and mutation operations are to be conducted in a different way. Many methods are available for cross over operation. Here Haupt's method is used. Assume there are two parent chromosomes a=[xa, ya] and b=[xb,yb] ,select parameter y randomly as the point of crossover. Then introduce a new random value α between 0 and 1, and the y values of the offspring are ynew1= (1-α)ya+αyb and ynew2=(1-α)yb+αya and the second parameter x is directly inherited from the each parent. So the off springs after the crossover are off spring1=[xa, ynew1] and offspring2=[xb,ynew2].

In mutation operation a new chromosome is created by introducing small diversity into a randomly selected chromosome. In GA, mutation introduces unpredictability in the results and hence the performance.

Data Base

Inductor L and capacitor C values are designed for the Buck converter at different input voltages. Buck converter is simulated with PI controller for a range of L and C values at each input voltage. From the waveforms of output voltage and current through inductor, peak value, percentage ripple and settling time for each set of L and

C values at a particular input voltage are measured. And the data base of measured parameters is formed.

IV. PROBLEM FORMULATION

The objective is to obtain the optimal values for Buck converter inductance L_{bu} and capacitance C_{bu} which give desired output voltage and inductor current with minimum transients like reduced peak values, percentage ripple and settling time. And subjected to constraints $L_{bumin} < L_{bu} < L_{bumax}$ and $C_{bumin} < C_{bu} < C_{bumax}$, L_{bu}, C_{bu} parameter values to be adjusted, $L_{bumin}, C_{bumin}, L_{bumax}, C_{bumax}$ are boundary values of the components. Generally, Genetic algorithm is applied to solve the problem having the optimization function as a function of decision variables and the solution is a numerical value, but in case of Buck converter the output wave form cannot be represented by a single number because of its characteristics. Therefore the output of the Buck converter is represented by the parameters such as average value, peak value, percentage ripple and settling time. The inductance L_{bu} and capacitance C_{bu} pair which give the desired values of the said parameters is the solution for the problem. And instead of simulating Buck converter for each pair of L_{bu} and C_{bu} values inside Genetic algorithm, it is simulated offline in advance and the parameters are stored in the database for a range of L_{bu} and C_{bu} starting from designed minimum values.

Procedure for obtaining the optimum values of the inductor and capacitor using Genetic Algorithm.

1. Specify Vin, peak value, percentage ripple and the settling time for the output voltage and inductor current

2. Initial population is created randomly, to represent the decision variables L_{bu} and C_{bu} with the constraints.

3. The randomly created values and database values of inductor and capacitor are compared for computing the Least Square Index L_{ind} .Inductance and Capacitance values which give minimum value of L_{ind} are found out by the following equation

$$L_{ind} = index\left[min\ i = 1 \ldots N\ \sqrt{\left\{\frac{L_{bui} - L_{bu}^{*}}{L_{bumax}}\right\}^2 + \left\{\frac{C_{bui} - C_{bu}^{*}}{C_{bumax}}\right\}^2}\right] \qquad (4)$$

Where L_{bu} and C_{bu} are the values of decision variables from the database

L_{bu}^{*} and C_{bu}^{*} are values created by Genetic Algorithm

L_{bumax} and C_{bumax} are possible maximum values of decision variables.

4. For this pair of inductance L_{bu} and capacitance C_{bu} values corresponding peak value, percentage ripple and settling time of the output voltage and inductor current have to be tested to verify whether they are within the limits.

5. If the database values of the above said parameters of the output voltage and inductor current are within the limits the algorithm terminates.

6. If the optimal values for the decision variables are not found with the existing population, mutation and crossover operations are to be executed.

7. Crossover operation produces new population for L_{bu} and C_{bu}.

8. With the second generation population, fitness function L_{ind} is calculated.

9. Mutation operation is executed on any one set of randomly selected decision variables.

10. With the mutated pair of L_{bu} and C_{bu} values fitness function L_{ind} is calculated.

11. Out of the Selection, Crossover and Mutation operations, the best pair of decision variables L_{bu} and C_{bu} which give best values of the desired parameters is chosen for the design of the Buck converter.

V. IMPLEMENTATION

Following parameters are used for the simulation of Buck Converter.

Parameter	Value
Vi - input voltage	200 volts,400 volts,600 volts
Vo - output voltage	110 volts
fs - switching frequency	50 kilo hertz
R- Load resistance	8.06 ohms
Lmin - minimum value of inductance	2 milli Henry
Lmax - maximum value of inductance	6 milli Henry
Cmin - minimum value of capacitance	2 micro Farad
Cmax – maximum value of capacitance	6 micro Farad

Following parameters are used for Genetic algorithm

Parameter	Value
Npar – number of parameters	2
Np – size of the population	50
Cp – crossover percentage	0.7
Mp – mutation percentage	0.2
Itr – number of iterations	1
Lmin - minimum value of inductance	2 milli Henry
Lmax - maximum value of inductance	6 milli Henry
Cmin - minimum value of capacitance	2 micro Farad
Cmax – maximum value of capacitance	6 micro Farad

VI. RESULTS

The following output voltage and inductor current waveforms are obtained after simulating Buck Converter for different input voltages.

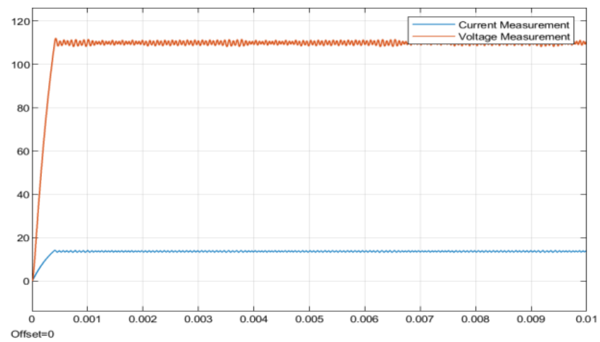

Figure.2 Vin=200 volts,L=4mH,C=2.5milli F

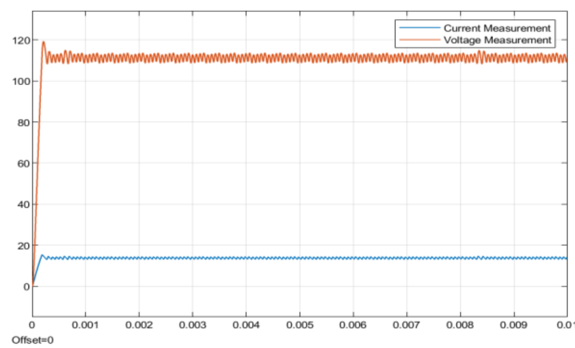

Figure.3 Vin=400 volts,L=6mH,C=5.5 micro F

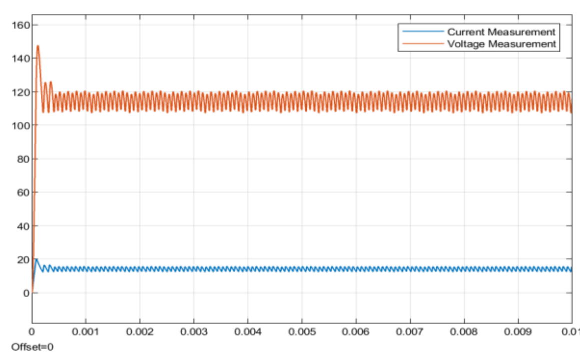

Figure.4 Vi= 600 volts,L=4 mH, C=2.5 micro F

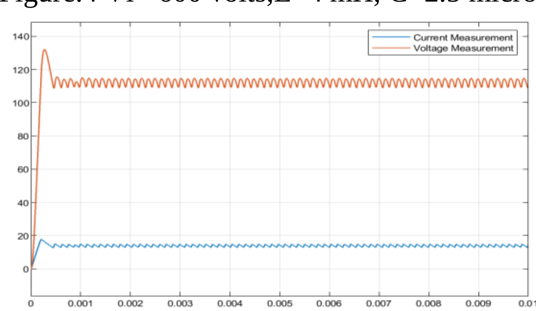

Figure.5 Vi= 600 volts,L=6mH,C=5.5microF

Table .1 Database values obtained after simulation of Buck converter at Vi=200 volts for different set of inductance and capacitance values.

L in milli H	C in micro F	Vp in volts	Ip in amps	Voltage ripple	Current ripple	Voltage settling time	Current settling time
5	4	140	15.2	2%	20%	0.0003 s	0.0003 s
4.5	4	142	15.8	2%	20%	0.0003 s	0.0003 s
4	4	146	16.2	2%	20%	0.0003 s	0.0003 s
3.5	4	150	17	2%	20%	0.0003 s	0.0003 s
3	4	158	18	2%	20%	0.0003 s	0.0003 s
2.5	4	164	20	2%	36%	0.0003 s	0.0003 s
2.0	4	164	20	2%	36%0	0.0003 s	0.0003 s
6	4	135	15	1%	<20%	0.0006 s	0.0006 s
6	6	144	16.2	1%	<20%	0.0008 s	0.0008 s
6	5.5	146	16.2	<1%	<20%	0.0008 s	0.0008 s
6	5	140	16.2	<1%	<20%	0.0008 s	0.0008 s
6	4.5	138	16.2	<1%	<20%	0.0008 s	0.0008 s
6	4	132	16.2	<1%	<20%	0.0008 s	0.0008 s
6	3.5	128	15.2	1.5%	20%	0.0008 s	0.0008 s
6	3	128	15.2	1.5	20%	0.0008 s	0.0008 s
6	2.5	126	15	1%	22%	0.0008 s	0.0008 s
6	2	124	15	1%	24%	0.0008 s	0.0008 s

From figures 2, 3, 4 and 5 it is observed that the inductance and capacitance pair which give best performance for 200 volts input will not give the same performance for the input of 400 volts. This variation in performance for input of 600 volts is shown in figure. 4 indicates increased peak values and percentage ripple. Figure .5 shows improved performance for different pair of inductance and capacitor values.

For the specifications of Vp< 130 volts, Ip<16 Amps, voltage ripple=20% and current ripple=2%, the Genetic Algorithm gave the optimal values of inductance and capacitance as 5.342 milli Henry and 3.428 micro Farad respectively. And the nearest inductance and capacitance values are 6 milli Henry and 3.5 micro Farad respectively from the data base table 1, the Buck converter inductance and capacitance values can be adjusted to these values to obtain the desired performance.

VII. CONCLUSION

A DC - DC Buck Converter is designed and simulated in MATLAB/Simulink environment at input voltage of 200 volts, 400 volts and 600 volts respectively to obtain 110 volts output. The Buck converter gives 110 volts output for the range of input from 200 volts to 600 volts with PI controller, but with increase in input voltage the performance i.e. the quality of the output reduces in the form of increased peak and percentage ripple of both output voltage and inductor current. By changing the values of inductance and capacitance peak values and percentage ripple of the output voltage and inductor current can be reduced. The optimal values of inductance and capacitance which give better performance at the increased input voltage are obtained by Genetic Algorithm. Since mathematical model of a Buck Converter is a differential equation, it is not possible to obtain solution for the optimization function directly. Hence in this paper Genetic Algorithm is used to find the optimal values of the variables which gives the desired performance with the help of a stored database.

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