Anfis Based Soft Switched Dc-Dc Buck Converter with Coupled Inductor

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Abstract:
Objectives: *ANFIS is growing and advanced modern computing tool for electronics world. The combination of both fuzzy interface and neural network to operate in many electrical and electronics system. ANFIS algorithm is controlling and modifies the output of the converter. It can be applicable in other type converter for voltage regulation. ANFIS is computing network with different input/output to obtain the appropriate value.*
Method/Statistical Analysis: *The enhance ANFIS logic is one of the developing techniques in combination of fuzzy interface signal and neural networks. ANFIS is computing network to obtain the appropriate value. ANFIS control algorithm is developed for soft switching and voltage regulation. Its dc-dc step down converter works in ZCS and ZVS condition at both on and off state. This converter can produce a high efficiency under heavy load conditions.*
Findings: *This converter includes simple construction of buck converter with coupled inductor and switch. And the switch is replacement of diode to obtain synchronous operation to avoid diode drop. Voltage regulation is obtained by ANFIS control algorithm. The overall performance and efficiency is improved by this method. This converter can produce a high efficiency under heavy load conditions.It can be applied in other types of converter such as dc-dc converters, regulator and motor controlling applications. It can be applicable many areas of power electronics such as RPS, battery charging, voltage regulation in solar plant and micro grid application.*
Application: *speed controlling of motor, regulated voltage, battery charging, regulated voltage for solar panel and converters, RPS and micro grid application.*
Keywords: *Buck converter, zero-current-switching, zero-voltage switching, coupled inductor, soft switching, ANFIS.*

I. Introduction:

In recent trends dc-dc converter plays a major role in the power electronics and controlling application. This can be used in many areas such as home application, industrial application and aerospace etc. There are several modification in the development of new technologies in power electronics to reduce the power loss, size, cost and improve the efficiency. The converter should be lighter in weight and to limit the switching losses. In case the switching frequency of the converter is high so the losses across the switch will be more, current ripple and efficiency is reduced. To avoid this frequency value is reduced by selecting the proper rank of switch and soft switching. In this paper ANFIS based dc-dc buck converter with coupled inductor obtained the regulated output with soft switching. And it can be applicable for many uses such as battery charging, voltage regulated for solar panel, RPS and micro grid application. In[1] Soft switching is the technique to avoid the losses across the switch during switching transition. The condition can be satisfied when voltage and current across the switch is maintained to zero value during turn on and turn off. The soft switching can be obtained by several methods such as zero voltage switching, zero current switching and quasi resonant converter etc.

In[2-3]The switching can be done by PWM dc-dc converter with switch mode operation. When the switch is turn off a large current flow through the switch which cause a switching stress, switching power losses and increase in switching frequency leads to switching losses and electromagnetic interference. The switching losses are reduced in the
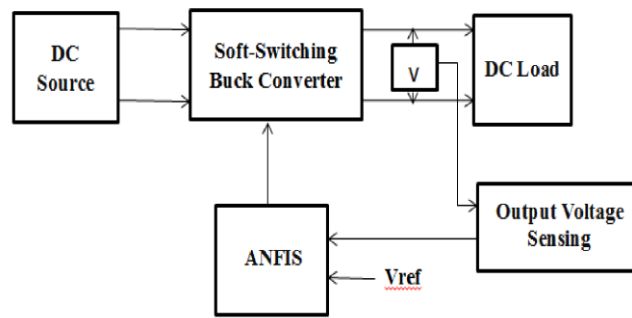
Figure.1. Block diagram of proposed converter

Resonant converter but the output voltage is not stable.In[4-5]Fuzzy logic techniques are used in the form of adaptive neuro-fuzzy inference system. In Proportional Integral (PI) Controller design of these controllers depends on selecting accurate PI gain values. Because these PI controllers are very sensitive to disturbances, parameter variations and system non-linearity. It causes difficulties in changing the value of the system. Here if-then logic is used for qualitative and quantitative improvement over other conventional techniques such as trial-and-error. In [6-7]In the quasi resonant converter the switching frequency is increased to avoid the fault of PWM converter by ZVS and ZCS. By using this switching transition with high frequency there are voltage stress and current stress in switch and overall efficiency is reduced. The converter consist two switches they are main switch and auxiliary switch, they turn on at zero voltage and turn off at zero current as switching transition. In[8-9] but the auxiliary switch operates under PWM mode due to that hard switching. If the both switch turn on at same period causes overlapping and short circuit in the output and rectified by selecting the proper rank of switch. In[10]An improved method zero current transition is applied for high power application but voltage fluctuation and small reverse voltage occur. Pulse width of switching device also varied. In this paper, the problems of light load are rectified based on ANFIS, an additional switch as MOSFET is used. The block diagram of proposed converter is shown in figure1. And the switching operation are performed under a ZCS operates during turn on, a ZVS operates during turn off and the output is regulated.

II. Proposed Converter and operations:

In the proposed buck converter topology is shown in figure2, it consist of three switches S1, S2 and diode D. The switch S1 and D act as a buck converter and S2 is auxiliary switch. Here switch S1 and S2 conduct alternatively. Two capacitors are used; C$P1$ is parasitic capacitance for MOSFET S1. Another snubber capacitor C$r1$ used to turn off the S1 under ZVS condition. There are three inductors L1, L2 and L3, L1 and L2 are coupled on the same core. L3 is the main inductor and its value is very small. ANFIS is used to regulate the output of converter. An output signal is feedback to the input of fuzzy controller.
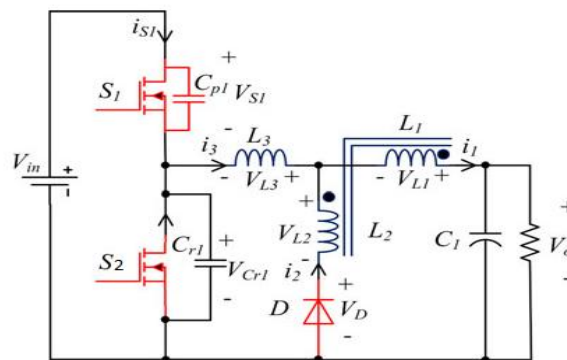

Figure.2. Circuit diagram of proposed converter

Modes Of Operation
Mode 1
The converter starts operating in current free -wheeling stage is shown in figure3 (a) and current i*3* and is*1* are equal to zero. During starting switch S*1* is turn on, due to *L3, is1* will increase slowly so *S*1 can turn on under a ZCS condition. And current *i3* and *i1* will increase, and *i2* will go down. Since *L3* is very small, the current-rising rate of *L3* is larger than that of L*1*. At this stage i*3* and i*1* are equal, and i*2* is zero. It means that D turns off. Based on KVL and KCL,

i*1*= i*2* + i*3*

$$Vo - VL1 - VL2 = 0$$
$$VL2 - VL3 - Vin = 0$$

Mode 2
The current *i3* and *i1* are equal, and both increase linearly. Now D is off, no current flow through *L2*. The switch *S*1 turns off. It is similar to that of a conventional buck converter in figure3 (b).
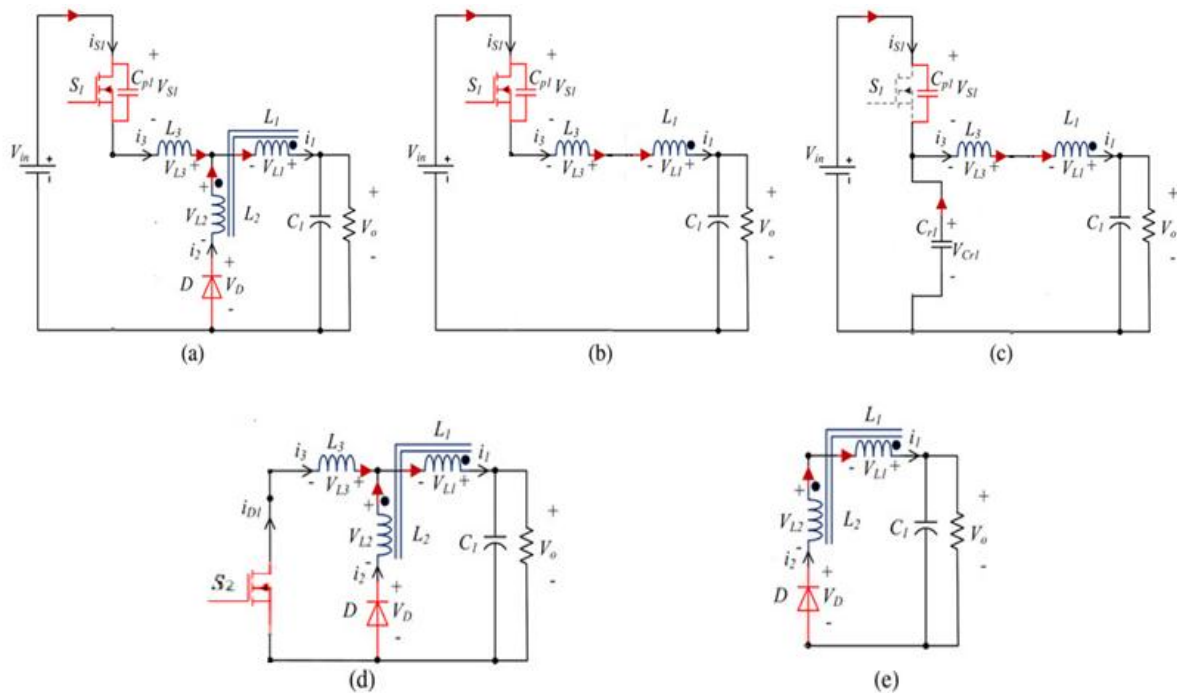

Figure.3. Equivalent circuits for each operation mode of buck converter.

Mode 3
The switch *S1* turns off and then a resonance occurs between inductors (*L1, L3*). *Cp1* is charged, and *Cr1* is discharged at the same time. When the voltage across *Cr1* reduces to zero,*S2* will conduct. This interval is very small so current does not change L*3*. Because *Cp1* is very small, it can be neglected.

From figure3(c),the voltage equations of inductors L*1*, L*2* and L*3* are expressed

$$V_{L1} = -L_1 \frac{di_1}{dt} - M \frac{di_2}{dt}$$

$$V_{L2} = -L_2 \frac{di_2}{dt} - M \frac{di_1}{dt}$$

$$V_{L3} = -L_3 \frac{di_3}{dt}$$

Where M is the mutual inductance and equal to square root of L*1* and L*2*.

Mode 4
When *S2* and *D* are conducting simultaneously and it is assumed that D could not turn on. The number of turns L*1* and L*2* are n*1* and n*2*. Then D conduct, voltage across the diode is zero.

V*o* – VL*1* – VL*2* – Vd = 0

The current *i3* will decrease much faster than *i1* because *L3* is comparatively small. As long as *i3* reduces to zero, *S2* will turn off, and the condition of ZCS for *S1* is achieved from figure3(d) shown.

Mode 5
From the shown figure3(e)the switch *S2* turns off, then a small resonance between *L3* and *Cr1* occurs, in which *i3* oscillates around zero and the amplitude is small. So *i3* is supposed to zero in this mode. The current just flows through *L1* and *L2* ,i1 is equal to i2 .

The above mode operates the main buck converter. This converter operates under closed loop control and main buck converter output is feedback to the fuzzy interfacing system. And the feedback voltage is regulated according to the reference voltage. According to the reference voltage the desired output are obtained from the ANFIS.

Design of Main Circuits and Analyses of Simulation Results
While designing the proposed converter, it mainly divided into two parts they are ANFIS controller and main circuit.
The main circuit is modified buck converter with three inductor, two switches, diode and capacitor. In this proposed converter soft switching is obtained and MOSFET switch are used. The selection of inductor L1, L2 and L3, the current in inductor L3 is small and reduce to zero. In the main circuit operation mode 3 and mode 5 are conduct for very small interval and its not considered while calculation for converter. The soft switching are obtained from ZVS and ZCS condition during turn and turn off of converter.

A. ANFIS
        Adaptive Neuro-Fuzzy Inference System (ANFIS) technique was introduced by Jang in 1993. ANFIS is a simple data learning technique and combination of Fuzzy Logic and neural network. Both method are combined as single technique and improve the quality of output. An ANFIS operates by applying Neural Network learning methods to improve the parameters of a Fuzzy Inference System (FIS). ANFIS network structure consist some set of rules and five distinct layers which makes a multi-layer structure are shown in figure 4. It mainly consists of two inputs and one output and produce an appropriate output.
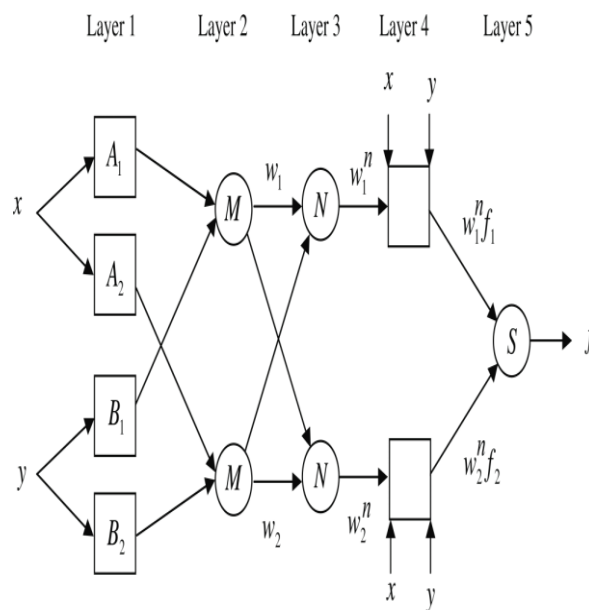

Figure.4. architecture of ANFIS

The applied fuzzy inference to modeling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model. In general the shape of the membership functions depends on parameters that can be adjusted to change the shape of the membership function. The parameters can be automatically adjusted depending on the data that we try to model. This system contains two inputs namely *x* and *y* and an output or *Z* which is associated with the following rules:

Rule 1 If (*x* is *A1*) and (*y* is *B1*) then *Z1=p1x+q1y+r1*
Rule 2 If (*x* is *A2*) and (*y* is *B2*) then *Z2=p2x+q2y+r2*

In this system, *Ai, Bi* and *Zi* are fuzzy sets and system's output respectively. *pi*, *qi* and *ri* are designing parameters which are obtained during the learning process. Suppose the collection of input/output data and would like to build a fuzzy inference model/system that approximate the data. Such a model would consist of a number of membership functions and rules with adjustable parameters similarly to that of neural networks. The neuro-adaptive learning techniques provide a method for the fuzzy modeling procedure to learn information about a data set, inorder to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. Using a given input/output data set, the toolbox function ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone, or in combination with a least squares type of method.

Table1. specifications of proposed converter

Parameters	Values
Vin	70v
Vout	36v
Poutput	250w
Fsw	20Khz
Iin	4.7amps
Iout	3.6amps

In this proposed converter of 200W simulated, and specifications are shown in table1. Applying this specified value into equations, the solved results are presented in the formula for the duty cycle in a buck converter, as *D = Vo/V*in.

III. Analysis of Simulation Result

The existing converter simulated output and output for different input voltage and load. The outputs of the converter varied according to load and loss occur in switch.

Table2. output of existing converter for different input and load

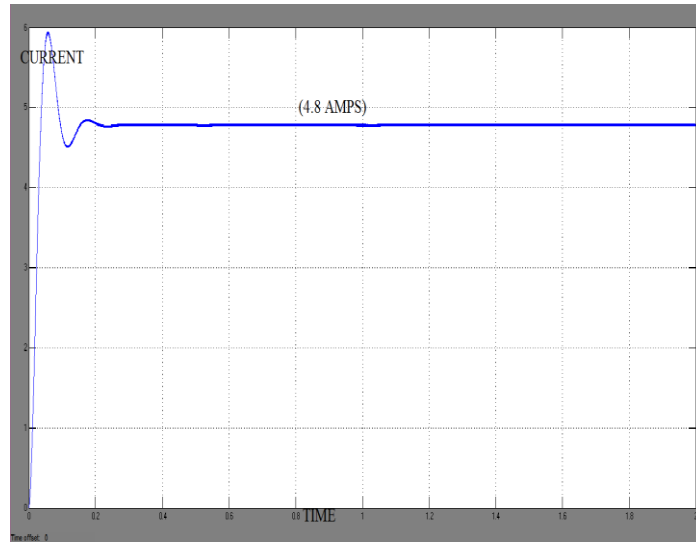| Input voltage (volt)	Input current (amps)	Output voltage (volt)	Output current (amps)	R load (ohm)
60	2.9	41	4.1	10
70	3.4	48	4.8	10
80	3.9	55	5.5	10
60	5.7	40	8	5
70	6.6	46.5	9.3	5
80	7.6	53	10.6	5

Figure.5. Simulation diagram of existing converter output current

The existing converter simulated output V=48v for the input of V=70v, and current value in the converter is 4.8amps are obtained. And the existing simulated output of current and voltage are shown in figure5 and figure6.
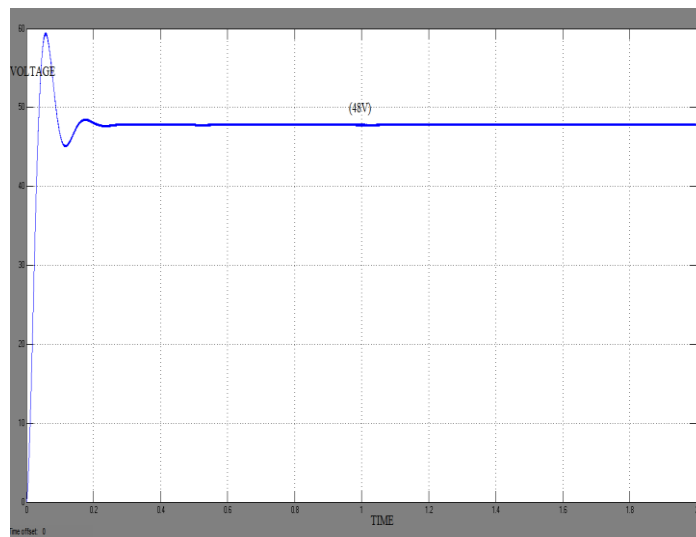

Figure.6. Simulation diagram of existing converter output voltage

The output for different load and voltage are shown in table2. For the short interval period current across the inductor L3 is zero. And results are obtained from MATLAB software.

Table3. output of proposed converter for different input and load

Input voltage (volt)	Input current (amps)	Output voltage (volt)	Output current (amps)	R load (ohm)
60	7	36	3.6	10
70	4.7	36	3.6	10
80	7	36	3.6	10
60	7	36	7.2	5
70	5.5	36	7.2	5
80	7	36	7.2	5

The proposed converter simulated output V=36v for the input of V=70v, and current value in the converter is 3.6 amps are obtained. The different value of input and load are shown in the table 3. The proposed simulated output of current and voltage are shown in figure7 and figure8. Results are obtained from MATLAB software and the values are shown in the above table 3.
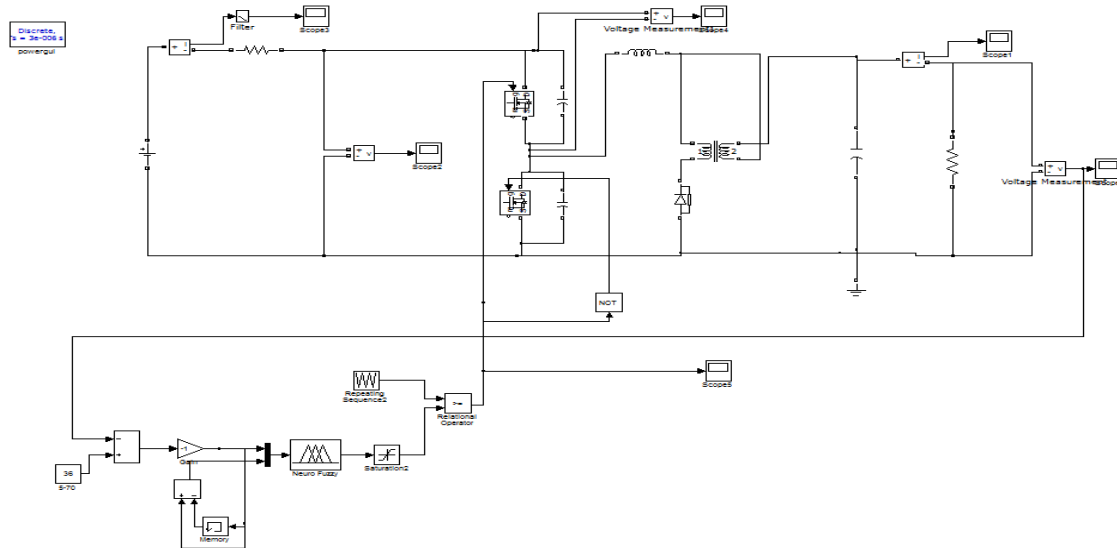

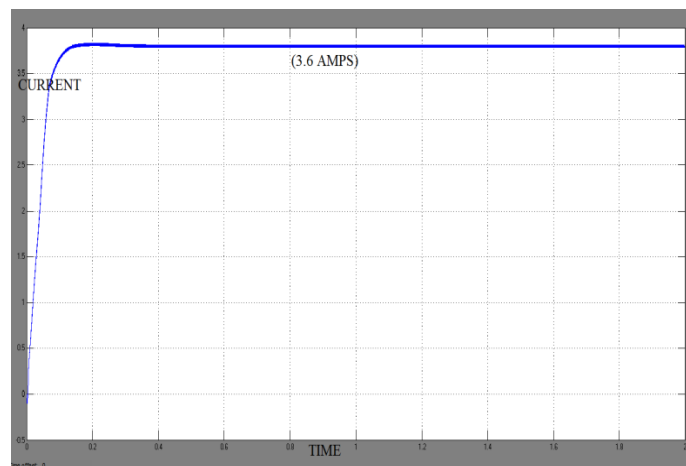**Figure.7.** Simulation diagram of proposed converter

Figure.8. Simulation diagram of proposed converter output current

The simulation diagram of proposed converter is shown in the figure 9 and outputs are obtained from this simulation. It is a closed loop circuit and buck converter output is feedback to fuzzy interfacing system to regulate the output voltage with reference voltage.

In this converter the unbalanced voltage at output side is rectified and maintained balanced value. The output voltage is regulated with different change in input voltage and load.
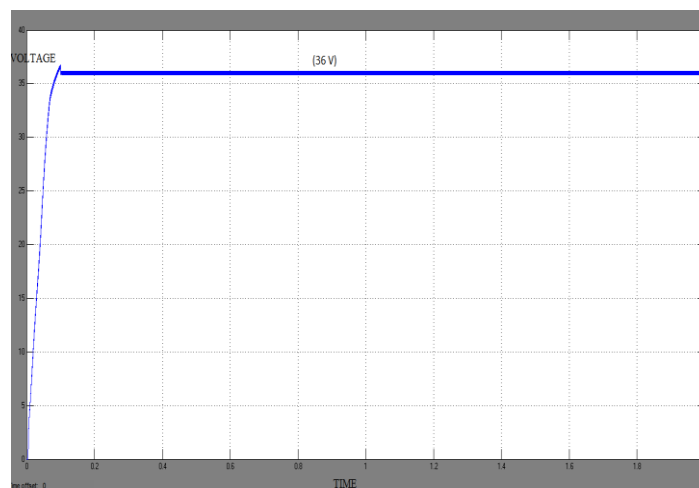
Figure.9. Simulation diagram of proposed converter output voltage

IV. Conclusion

In this method, an ANFIS based soft switching buck converter with coupled inductor has been developed. The design of the main circuits and operating principles are discussed. By making inductor *L*3 to work under DCM, ZCS turn on and ZVS turn off for *S*1 are achieved. The simulation outputs of proposed converter are verified with existing system. ANFIS is adaptive neural network of fuzzy interface logic with logic rules. It's closed loop operation and easily controlled over the unbalanced voltage at the output side and output results. Due to ANFIS controlling is easy. The voltages are varied for different load and improved its voltage regulation.

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