# Three-arm AC-DC-DC Automatic Voltage Regulation with Current Ripple Reduction Technique Topology

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***Abstract*—The aim of this paper is develop the three-branch Alternating current Automatic Voltage Regulator(AVR) with fuzzy logic technique. Based upon this technology AVR controller has been developed and simulated to decrease the switching power losses across the switches. The proposed fuzzy controller based AVR has the ability of producing the sinusoidal output current with better output voltage regulator. This three-branch power convertor circuit acts as an AC step up (boost ) converter when the supply voltage is less than the load voltage and acts as an Alternating current step down (buck ) converter when the supplied voltage is higher than specified value. Hence, the AVR output voltage maintained at a constant value. So, there is no need to use the large Direct current capacitor to withstand the continuous dc voltage. Hence, the size and cost of the converter is decreased and the life of the power converter is increased to analyse the THD.**

***Keywords—Current Buck, Boost, power converter, Automatic Voltage Regulator,THD***

## I. INTODUCTION

Now, a days the quality of the supplied power is very crucial to many consumers. The quality power (PQ) is solution and many customer are ready to pay for it. In future, Distribution System operators required orcould decided by the authorities to supply their customers with different power quality level of the various tariff's. the aim of three-branch AVR acts as boost power converter when the source voltage is less than the load voltage i.e. specified voltage and acts as buck power converter when the source voltage is higher than the output load voltage. Hence, the load output voltage is kept at constant level by using the automatic voltage regulator. The load demand is supplied by the conversion output of the power converter circuit ac-ac with conventional three-arm power converter which required twice conversion i.e. AC-DC and DC-AC. The purpose of this power converter is only one conversion. Beside, the power electronic switches a single branch of the three-branch power converter are operate at high frequencies while the other are operated at the lower frequencies. Which decrease the switching power losses and not required the transformer. In differentiation with typical three-arm AVR with a continuous bus DC voltage. The bus DC voltage of the proposed three-arm AVR is full wave rectified output voltage. Hence, the use of large direct current capacitor withstand a continuous dc voltage is avoided and only small direct current (DC) capacitor is employed to act as snubber and the filter circuit. So, three -branch AVR has the merits of decreasing the installation and volume ,as well as improve the reliability and efficiency. The protype is developed and examine.

## II. FUZZY SET THEORY

a. **Fuzzy setDefinition**:-A fuzzy set is a part of (u,m) where u is a set and m is membership function which is ranges from 0-1. The reference set (u)is called the universe of discourse such that $x \in u$. The m(x) is the grade value of membership x in (u,m),function $m = \mu_A$ called as membership function fuzzy set and given as
A=(u, m) where u={x1,……xn} and m={m(x1),……m(xn)}……………….1

b. **OPERATION OF FUZZY SET :-**
Two sets A and B the universe of information u and an element of x of universe. The following relation can be performed they are union(OR),intersection(AND) and complement(NOT)

a) **Fuzzy OR operation :**let the sets A and B can be represented for OR operation is given by
$\mu_{A\cup B}(y)=\mu_A V \mu_B$………………..2
such that y belongs to u
Where ,V is maximum operation

b) **Intersection operation:** the two sets can be related by AND is expressed as
$\mu_{A\cap B}(y)=\mu_A \wedge \mu_B$………3
where ,∧ is minimum operation

c) **Fuzzy complement :** the complement of degree of membership in (A) is given as
$\mu_A = 1 - \mu_{A(y)}/y \in u$…….4

## III. CONTROLLER BASED ON FUZZY LOGIC :-

This controller is algorithm based in which a sets of rules are representing a decision and controlling mechanism to vary response of certain system. The purpose of fuzzy controller system is to replaced the human employment with a rule-based fuzzy logic system. This control logic works with algorithm which is developed in the controller unit convert is to performs the certain controlled operation on automatic control strategy based on required by the user. The below figure(1)shows the basic architecture of the fuzzy logic which includes the input module, fuzzification unit, interfacing, Decision-control logic, Defuzzification and output module.

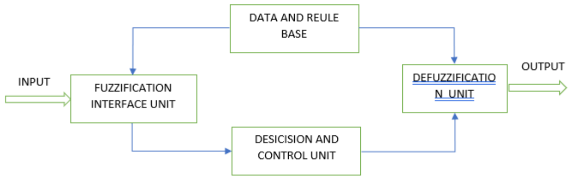


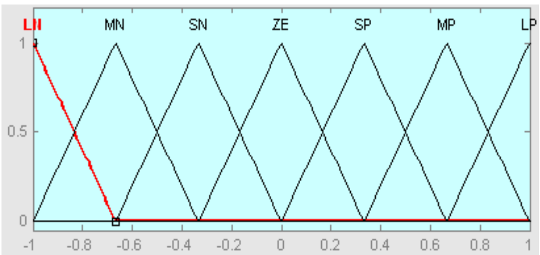

Figure (1):Architecture of fuzzy logic

## IV. AUTOMATIC VOLTAGE REGULATOR BASED ON FUZZY LOGIC :-

For develop the AVR based on fuzzy to select the state variable, which indicates the dynamic system. It should take the input signal for controlling. The next, is to select the semantic variable considering in the mind that required number of semantic declared the controlled standard. The compilation ,run time and as well as memory required is also increase. Hence, compromise the computational time is required to select the number of semantic variable. For this test system seven linguistic variables for each input and output variables are needed. Theyare as follows

i. Large positive
ii. Medium positive
iii. Small positive
iv. Zero
v. Large negative
vi. Medium negative
vii. Small negative

For normalization is done by dividing the input value by max of the corresponding value of the input variable by open loop simulation. The last, is to determine the membership function of the fuzzy sets. In this paper ,the rule-based system which uses the triangular member ship function for describing the degree of member as shown in figure(2).



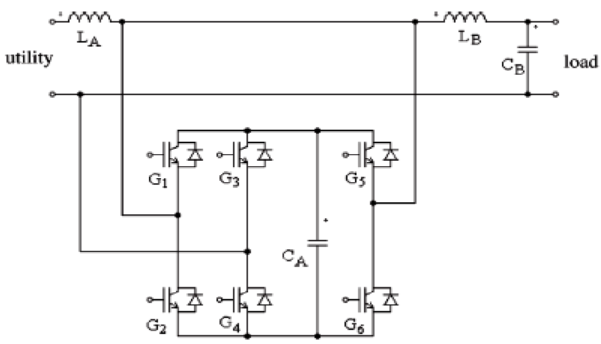

Figure(2): Input output membership function of the triangular wave

For designing the AVR the rule are describe by using semantic variables. The two inputs required ,error of deviations and their derivatives results 49 rules for each of the machine. These rules are properly describe in the table(1) below. The standard rules has following structure.

| Control $e$ \ $\Delta e$ | NL | NM | NS | ZR | PS | PM | PL |
|---|---|---|---|---|---|---|---|
| NL | NL | NL | NL | NL | NL | NL | NL |
| NM | NL | NL | NM | NM | NS | NS | NS |
| NS | NL | NM | NM | NS | NS | NS | ZR |
| ZR | ZR | ZR | ZR | ZR | ZR | ZR | ZR |
| PS | ZR | PS | PS | PS | PM | PM | PL |
| PM | PS | PS | PS | PM | PM | PL | PL |
| PL | PL | PL | PL | PL | PL | PL | PL |

Table(1): standard rules for fuzzy sets

The minimum and maximum technique is used for searching the fuzzy region for each of the rules and follows the intersection (AND) operation which gives the minimum between the two membership function.




Figure(3): The three-branch automatic voltage regulator circuit diagram

## V. CONFIGURATION AND THEORY OF OPERATION

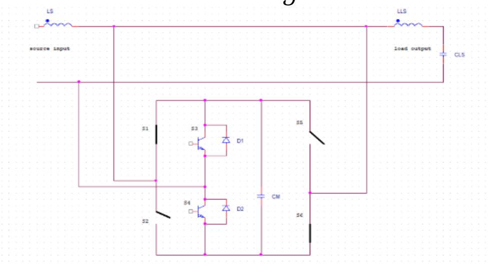
The proposed circuit is shown in the above figure(3). The three-branch AVR is shown in the figure. This AVR consists of three branches power converter, source inductor, small direct current capacitor and output filter. This AVR act as boost converter when the source voltage is less than the load voltage and acting as a buck converter when the supply voltage is higher than output load voltage hence the converter maintain the specified voltage at constant level so the power converter performs the alternating current boost as well as buck converter which is fully rectified DC output voltage of the AVR. It is different from the typical three-branch AVR’s with a continuous output DC voltage.

### a) Boost mode operation

In this mode of operation the converter acts as boost i.e. when the supply voltage is less than the load voltage. In this condition the first and the third branches are controlled by square wave signal with the fundamental frequency of the utility and the second branch is controlled bypulsewidth modulation technique which employed higher frequency. The below figure(4a) shows the boost operating mode of the converter. The source inductor $L_s$ which is acting as energy storing element. Figure (4 a) shows the positive half cycle operation in boost mode. Here, the switches S1 & S6 are in conduction mode always. Switches S2 & S5 are in off states. When the S3 is at conduction mode and S4 is in off state. The source voltage makes the inductor to energies during the period S1 and S3. The voltage is given as

$V_{LS} = V_S$ ..................................5

Where , $V_{LS} = voltage\ across\ inducyor\ and\ V_S = source\ voltage$



Figure(4a):circuit diagram for AVR for and AC boost mode for positive cycle

The current through inductor is increase and make the conduction of the S2 and S4 to the dc capacitor of the converter when S3 is non-conducting mode and S4 is in conduction mode. The voltage across inductor is given by

$V_{LS} = V_S - V_C$ ...................6

$where, V_C = voltage\ across\ capacitor$

Hence, the output voltage is higher than the input source voltage under the boost mode power converter, the inductor current is reduced .for continuous mode of current is flowing through $L_S$ Volt sec balance from faraday's law is given by

$V_S T - V_C T(1-D) = 0$..............7

D is the duty cycle ratio ,T is time period of the S3.

Form the $eq^n$4 the gain of the converter is given by

$M_V = \frac{1}{1-D}$ .......................8

The operation of the DC-DC boost converter is same as that of an AC boost during negative half-cycle. As shown in the figure (4b) having the same gain and the ripple current factor is given by

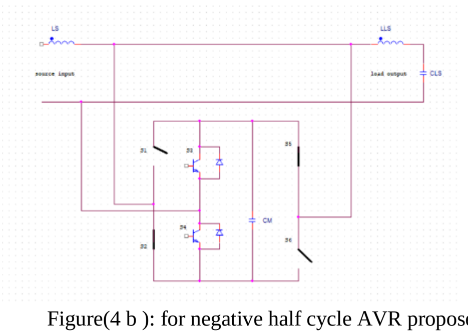
$\Delta_{ILS} = \frac{V_S DTT}{L_S}$ ...................9

$where\ , \Delta_{ILS}\ is\ the\ current\ ripple$

Which depends on the duty cycle ratio the minimum value of the inductor is given by

$L_{S\ minimu} = \frac{D(1-D)^2 Z}{2F}$ ..........10

Where, F is switching frequency ,Z is the load impedance, the $L_{LS}$ and $C_{LS}$ are the low pass LC filter to reduce the harmonic of the DC capacitor voltage $C_M$ which is tens of the $\mu f$ can be used .



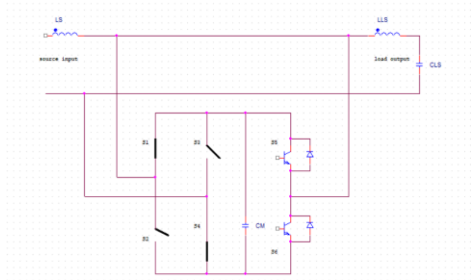
Figure(4 b ): for negative half cycle AVR proposed circuit diagram

**b) Buck mode operation**

When the input voltage is greater than the output load voltage,the buck power converter is used for step down of the voltage. Here, the 1st and 2nd branch is controlled by square wave signal with the fundamental frequency. The 3rd branch is controlled by the pulse width modulation technique which use the higher frequency. The $L_{LS}$ is acting as energy storing element when the power converter is operated in buck mode. The below figure(5 a) shows the operation of the buck under the positive half cycle of the input source voltage. The switch S1 & S4 is in conduction mode always and S2 and S3 is in non-conduction mode always. The 1st and 2nd branch is used to rectified the input source and appearing as bus DC voltage. $L_S$& $C_M$ is acting as the LC-LPF. When S5 is on and S6 is in off,then$L_{LS}$ stores the energy from the dc bus via S4 and S5. In this period load side inductor $L_{LS}$ voltage becomes

$V_{L_{LS}} = V_C - V_0$ ..............................11

Where, $V_0$ is the output load voltage



Figure(5 a): proposed circuit diagram for positive half cycle of buck converter

$\therefore\ V_{dc} > V_0$ in this period $L_{LS}$ stores the max energy in the inductor and discharge through the path S4 & S6 when S5 is off and S6 is on. The voltage across inductor becomes

$V_{L_{LS}} = -V_0$ ...............12

For continuous current flowing through the inductor makes the volt-sec-balance according to faraday's low and given as

$V_C DT - V_0 T = 0$ .............13

Where, T and D are the duration of switching and duty ratio of S6 respectively. The gain dropped becomes

$M_V = D$.............14

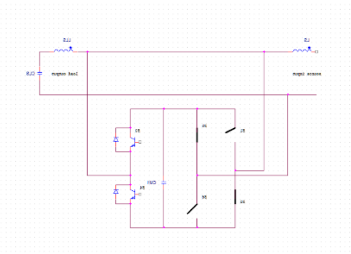
For negative half cycle of input voltage as shown in the figure(5 b) .S2 & S3 are in always in conduction mode, while S1 & S4 are in off state always. The 1st and 2nd branch is used for rectification which is utilized by the $L_{LS}$ to stores the energy via S3&S6 when S5 is off and S6 is on. The stored energy is discharge through S3&S5 when S5 is conducting and S6 is non-conducting mode. It is same as the operation of the negative half DC-DC buck converter. Hence ,the output voltage is less than the input source voltage of the three-branch power converter circuit.

The minimum value of inductor for continuous conduction mode is given by

$L_{LS_{MINIMUM}} = \frac{(1-D)Z}{2F}$ ..........15

And the ripple output load voltage is given by

$\Delta_{V_0} = \frac{(V_C - V_0)D}{8 L_{LS} C_{LS} F^2}$ ........16



Figure(5 b): AVR proposed circuit diagram for negative half cycle of buck converter

## VI.SIMULINK MODEL OF THE SYSTEM

The Simulink model of the system is shown in the figure(6) which is proposed by AVR. It consists of input voltage selection unit, output load voltage processing unit ,and the selection unit. The square wave signal is generated form the input source which uses the voltage sensor. These, signal is usually operated at low frequency. The output form the voltage sensor is passed to the Zero-crossing phase detector and the synchronization is done by inverting the signal with the input source. For obtaining the circuit driving signal to S1 and S2 of the 1st branch. The output from voltage sensor is send for selection and generation of signal 1. The signal 1 is used for the operation of the three- branch AVR power converter. If the input voltage is less than the input voltage then converter is operated in boost mode, else in buck mode. Here, the input voltage is higher than the output load voltage. The required parameter of three-branch AVR shown in the below table (2) .

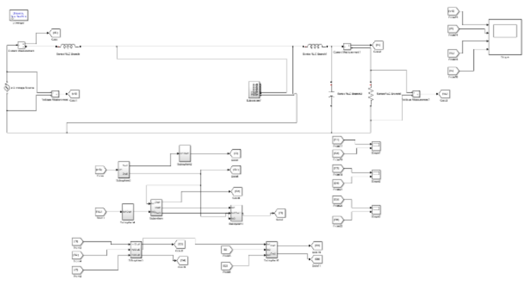


Figure (6): Simulink model of the AVR based on fuzzy controller

| | |
|---|---|
| Input source inductor $L_S$ | 0.4e-3 H |
| Load side filter inductor $L_{LS}$ | 0.4e-3H |
| Load side capacitor filter $C_{LS}$ | 20e-6 f |
| Middle dc capacitor $C_M$ | 20e-6 f |
| Pre-define load output voltage | 110 V and 60 Hz AC |
| Pulse width modulation technique | 20e3 Hz |

Table (2): important parameter of the proposed AVR

## VII. RESULT

The performance of the proposed AVR has been developed and simulated successfully. The controlling function is carried out with the help of the fuzzy logic based controller

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