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Performance Evaluation of GA Based PID Controlled Power Convertor Application to Air Breeze Wind Generator

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Abstract: Renewable power generation systems such as Wind Generator (WG) often experience big changes in the inverter input voltage due to fluctuations. As the air flows on top of the hills and down valleys, strong updrafts, downdrafts and eddies are developed. Due to the change in direction and speed of the wind, wind turbine is subjected to fluctuation in the wind generator. DC to DC boost converters are used to step up the voltage from a DC source like battery or DC wind generator to match the operating voltage range of inverter and constant voltage DC loads. This paper proposes a novel Genetic Algorithm (GA) optimized Proportional Integral and Derivative (PID) control Pulse Width Modulated (PWM) technique used converter is applied in the proposed DC Wind Generator (WG). This system is used in remote areas like forest department on hill tops to give power supply under breeze air conditions. It has less switching loss, less settling time and high efficiency during the transient period. Parameters used are investigated, K_p,K_i and K_d parameters are optimized by GA, theoretical analysis with simulation results in Matlab simulink and experimental results are obtained to verify good performance.

Key words: Breeze Air · DC to DC boost converter · GA · PID controller · PWM · Matlab simulink · WG

INTRODUCTION

To face the energy needs of present scenario, it is important to enlarge them with new solution. To generate power on a large scale, alternative sources like solar and wind are highly useful. However, common drawback with solar and wind energy are unpredictable in any area. They depend on weather and climatic changes of the environment [1]. Even at the best wind sites, there are fluctuation in speed and change in direction of the wind which affect the ability of the wind turbine to deliver power [1].Larger wind turbine systems have complex control systems which automatically track changes in speed and wind direction and adjust turbine orientation, pitch angle and generator gear ratio to maintain the desired electrical output. Small wind turbine systems are typically much less complicated; however they in general still have some form of control to improve their long life and power generation. The major purposes of a controller in a wind energy system are [2]:

- To prevent wind turbine from damage
- To prevent load from damage
- To maximize power generation.

In the hills, the WG can benefit from height as being installed on top. Directional winds, rising winds, added to provide a force of 200%.But we must give attention to the shape of the land, because a hill area can encourage the inflow of wind, but a steep slope can be in the way considerably changing wind direction and then the force that will come to the wind generator (WG). In this case there will be wind but with whirling motion that goes at the expense of production. If the generator is installed downstream hill; the cross wind define strength of the wind generator. If the wind is blowing in the direction of the furrow, diagonally to the hills, they can convey a great deal of energy on the wind generator [2]. If the wind is not across the hills will turn aside the wind direction. If the height increases from the ground, the wind speed increases progressively. Because the terrain

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and various obstacles are hinder the wind and often provoke uncontrollable vortices. Then the generator should be placed as far away as possible from any obstacles and as high as possible [3].

Standalone photovoltaic (PV) or wind energy systems are not possible to produce energy for considerable portion of time during the entire period of the day. The proposed wind generator is mainly used on the hill top for providing power supply to forest department. This design is highly suited for breeze air condition so that it can be disturbed easily by the above mentioned problems on hills. To utilize the renewable energy resources, efficiently and economically an optimum match design method is needed and to utilize the power even in the various situation of transient period [4-5]. In this article the novel PID controlled PWM boost converter is presented with minimum switching losses and input power loss. When the uses of step-up type converters are necessary, a boost converter is conventionally used. However, the efficiency of a boost converter under normal condition is less than 94% [6-7]. For a better efficiency, it is possible to use MOSFETs with a lower resistance and Schottky diodes, but this is not economical because the input power taken in it is somewhat high compared to the proposed method. In order to increase the efficiency of the converter a novel GA based PID controlled PWM technique are used in the DC-DC converter. In this method the frequency of the converter is maintained as high as 100 KHz [8-9]. The compared efficiency curves are drawn for simulation and the experimental model efficiency curve al so plotted to verify the better performance.

Proposed Wind System: A schematic diagram of a stand-alone wind system is shown in Fig. 1.Wind Generator (WG) is directly connected with the boost converter without connecting the batteries. Boost converter is used to boost the voltage during the transient period when the wind force low to maintain the constant voltage across the DC loads. Other side of the boost converter the load can be connected. Controller is connected between the output and input of the converter; it is to generate respective correcting signal to pulse generator in order to maintain the voltage to be constant during transient period.

Now the pulse generated from the controller along with PWM has been used for triggering the switching device. Normally the switching losses play a major role in converters. And voltage rise than the required voltage also happened it will affect the load equipments. But in this proposed novel GA based PID controller with PWM technique reduces the switching losses and avoiding the voltage raise than the required voltage and generating the high quality output power supply.

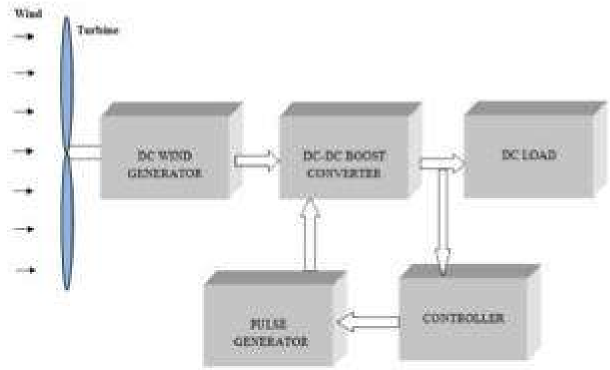

Fig. 1: Proposed Wind generator with novel boost converter

Proposed Wind Generator: The wind speed distributions for selected sites as well as the power output characteristic of the chosen wind turbine are the factors that have to be considered to determine the wind energy conversion system power output. Choosing a suitable model is very important for wind turbine power output simulations results [10]. The most simplified model to simulate the power output of a wind turbine can be described by (1).

$$P_W(V) = \begin{cases} P_R[(V^2 - V_C)/V_R{}^2 - V_C{}^2]; & V_C \le V \le V_R \\ P_R; & V_R \le V \le V_F \\ 0; & Otherwise \end{cases} \quad (1)$$

Where P_R is the rated electrical power; V_C is the cut-in wind speed; V_R is the rated wind speed; and V_F is the cut-off wind speed. In this study, the adjustment of the wind profile for height is taken into account by using the power law that has been recognized as a useful tool to model the vertical profile of wind speed. The equation can be formulated as in (2).

$$\frac{V(H)}{V(H_{ref})} = \left[\frac{H}{H_{ref}}\right]^p \quad (2)$$

Where *V(H)* is the wind speed at hub height H, m/s; $V(H_{ref})$ is the wind speed measured at the reference height H_{ref}, m/s; *p* is the power law exponent. It is very important determination *p* value. The value of 1/7 is usually taken when there is no specific site data [10].

Mountain regions exhibit many interesting weather conditions. One example is the valley wind, which originates on South-facing slopes (North-facing in the Southern hemisphere). The density of the air decreases, if the slopes and the neighboring air are heated and the air ascends towards the top following the surface of the slope. During night the wind direction is reversed and it turns into a down-slope wind. When the valley floor is sloped, the air may move down or up the valley. If winds flowing down the leeward sides of mountains, it can be quite powerful for operating the proposed Wind Generator (WG). Wind Generator Air Breeze 24V DC M15 is considered as wind generator model for the proposed wind generator, parameters of this model is shown in Table 1. Air Breeze produces absolutely non-polluting electric power, because no fossil fuel is burned to produce energy. Fossil fuels release carbon dioxide into the atmosphere. By Air Breeze wind generator and the power of the wind, we can forget our environmental footprint. The new Air Breeze, quieter, more efficient, designed specifically to provide more power with weaker winds than other wind generator in its category.

Table 1: Parameters of the DC Wind Generator

Model	Wind Generator Air Breeze 24V DC M15
Power	3200 HA to 5.8 m/s
Rotor Diameter	1.17 m
Dimension	686 x 318 x 229 mm
Weight	5.9 Kg
Support	48 mm outer diameter
Speed	3.13 m/s
Voltage	24V DC
Maximum Permissible Speed	49.2 m/s

Conventional Convertor: The conventional boost converter is designed with a small input and output filter. These filters are used to maintain the constant input current and constant output voltage. It is working in the general mode of operation, where the PWM operates with respect to the fixed K_p,K_i and K_d values of PID converters at the constant frequency variable pulse width mode as shown in Fig. 2. During the positive voltage of the firing circuit the MOSFET switch S_1 will turn on. This operation is named as mode I operation where in the inductor L will charge the current from the source. As long as the switch is turn on, the inductor will be charging. When the firing signal voltage reaches zero the switch S_1 will turn off. This operation is called as mode II [11-12]. During the second mode of operation, due to the charged current in the inductor L, it has inductor voltage across it. Now the wind generator voltage along with inductor voltage is discharged across the load. It is designed in the simulation model for the frequency of 100 KHz in matlab simulink. The output wave form of this converter is shown in Fig.3. However, in this method the major drawback obtained is the voltage rise during transient period is greater than the reference voltage, which leads to more loss across the switch and damage to the load components. But in our proposed converter the above drawback can be reduced and obtain better efficiency.

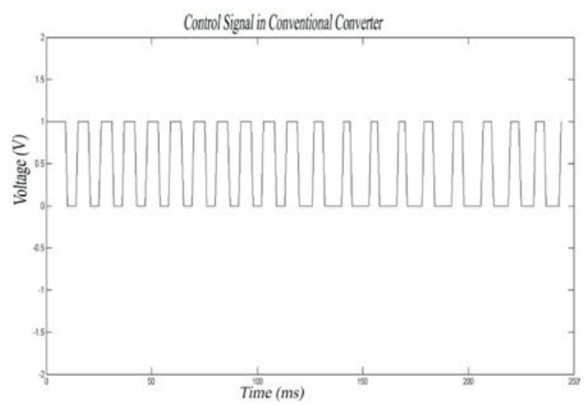

Fig. 2: Control signal in conventional converter

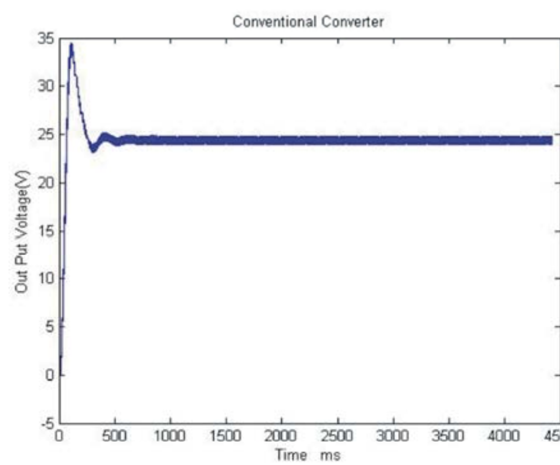

Fig. 3: Voltage wave form of the conventional converter

Proposed Convertor: The proposed converter is designed with GA based PID controller as shown in Fig. 4. Where the output voltage obtained from the converter is taken as the feedback and it is compared with the reference voltage what we need. The error signal is generated by comparing the measured voltage and the reference voltage.

As shown in the flow chart Fig.5 the genetic algorithm is optimizing the, K_p K_i and K_d values for every fluctuation in input of the converter. From the above optimized value, the PID controller is tuned and it generates the signal for the PWM. The PWM generates the resultant gate signal, is shown in Fig.4 for producing the required voltage as output. The PWM signal will be given to the main switch S_1, so that it will turn on when the signal is in high. During the turn on time the inductor L will charge the energy. Now the switch S_1 gets turn off. During that time the voltage across the inductor along with source voltage is passed through the load. Now the load gets constant voltage across it and with less settling time during transient. The main advantage of this proposed converter is, during the transient period it never raises the voltage more than the required voltage unlike conventional one. Efficiency is also good in it.

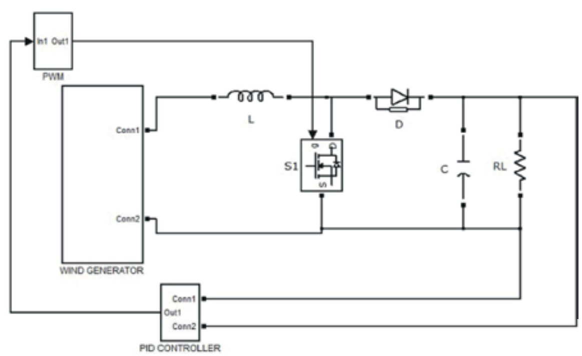

Fig. 4: Proposed GA based PID controlled PWM converter

Flow Chart of the Proposed Technique:

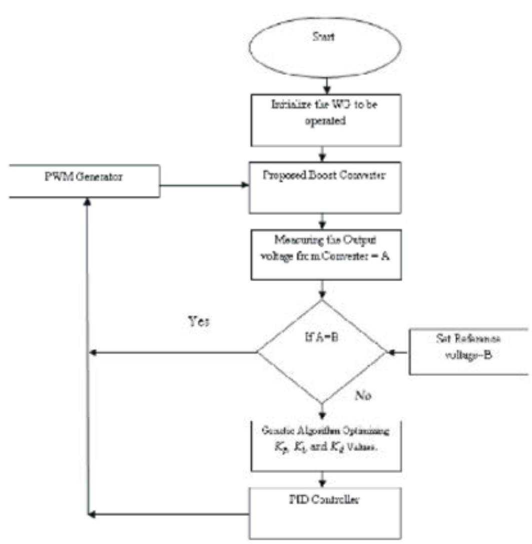

Fig. 5: Flow chart of proposed converter model

The entire working principle of the proposed converter has been depicted in the flow chart shown in Fig.5. Where, as long as the measured voltage is not being equal to the reference voltage the GA tunes the PID controller parameters, K_p,K_i and K_d values. The PID based PWM generates the control signal for matching the measured voltage from the converter to the reference voltage.

Genetic Algorithm: In the field of artificial intelligence, genetic algorithm (GA) is a search heuristic that imitates the process of natural selection. To derive useful solution to optimization and search problems, this heuristic is generally used. Genetic algorithm is the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques stimulated by natural evolution, they are inheritance, mutation, selection and crossover. The evolution algorithm generally starts from a population of randomly generated individuals and it is an iterative process, with the population in the each iteration is called a new generation. The fitness of every character in the population is being assessed in all the generation; the fitness is generally the value of the objective function. The more fit individuals are deterministic process selected from the existing population and each individual set of chromosomes is personalized to form a new creation. In the next iteration of the algorithm, the new creation of candidate solution is used. Generally, the algorithm stops either a maximum number of generations has been produced, or a reasonable fitness level has been reached for the population.

A Typical Genetic Algorithm Requires:

- A genetic representation of the resolution domain,
- A fitness function to weigh up the solution domain.

A typical depiction of each candidate solution is an array of bits [13]. Arrays of other types and structures can be used in actual fact. The very important property to make these genetic representations suitable is that their parts are easily allied due to their fixed size, which provides simple crossover operations. Variable length depictions can also be used, but in this case crossover implementation is highly complex. In genetic programming, Tree-like representations are used and in evolutionary programming graph-form representations are used; a mix of both linear chromosomes and trees are explored in gene expression programming.

In this proposed method, the transfer function of proposed boost converter has been derived and with respect to that the K_p,K_i and k_d values are optimized. The optimization has been done by using normal geometric selection method. Since this technique is highly suited for the optimization like converters to produce better accuracy, it is being selected for this method. Population size for this method used is 80 and number of generation taken is100. Arithmetic cross over method and uniform mutation methods are used since it gives high accuracy. The obtained K_p,K_i and k_d values are shown in the Fig.6. The step response for the PID converter is plotted and shown in Fig.7.

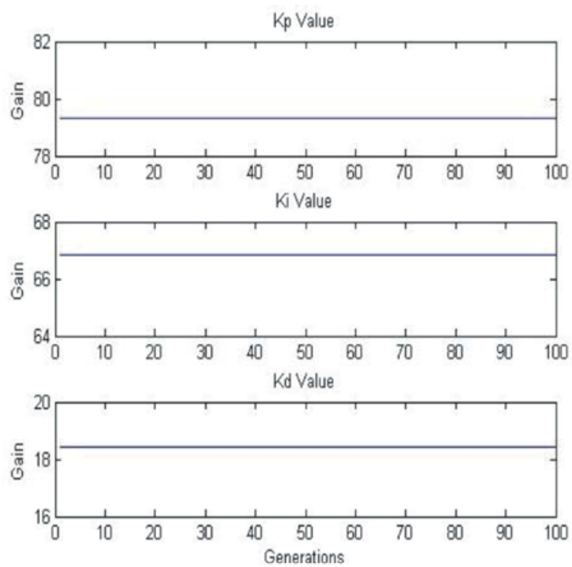

Fig. 6: GA optimized K_p,K_i and K_d gain values

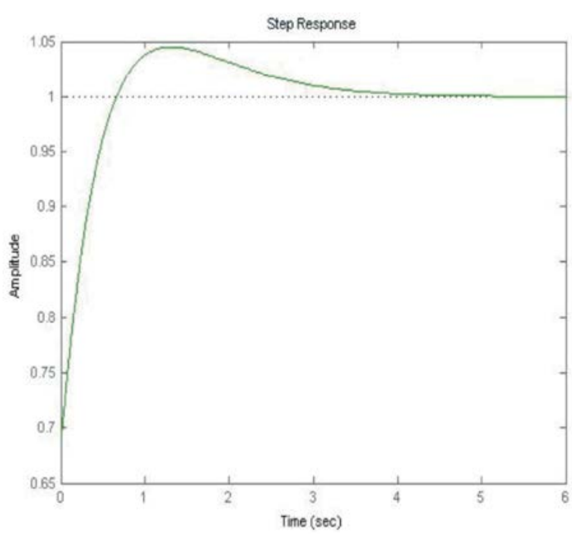

Fig. 7: Step response of the PID controller

PID Controller: A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism (controller) broadly used in industrial control systems. PID controller calculates an error value as the difference between a measured process variable and a preferred set point. By adjusting the process control inputs, the controller attempts to minimize the errors.

The PID controller calculation algorithm involves three separate constant parameters; hence they sometimes called three term control. They are proportional, the integral and derivative values, denoted *P, I* and *D*. In simple, these values can be interpreted in terms of time, *P* depends on the present error, *I* depend on past errors and *D* is a prediction of future errors, based on current rate of change [14]. The sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a inductor.

The PID control scheme is named after its three correcting terms; sum of these constitutes the manipulated variable (MV). The proportional, integral and derivative terms are summed to calculate the output of the PID controller [14]. Defining $u(t)$ as the controller output, the resultant form of the PID algorithm is given in (3).

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt}e(t) \quad (3)$$

Where

K_p: Proportional gain, K_i: Integral gain, K_d: Derivative gain

e: Error = $SP - PV$

(SP: Set Point, PV: Present Value)

t : Time or instantaneous time (the present)

τ: Variable of integration; takes on values from time 0 to the present t. The proportional term produces an output value that is proportional to the current error value.

Table 2: The gain constants for various currents

Load current in Amps	K_p	K_i	K_d
1.0	50.75	91.23	9.376
1.5	85.24	90.62	56.56
2.0	83.5	73.1	22.43
2.5	82.9	83.6	20.9
3.0	77.24	88.83	19.51
3.5	86.47	54.51	85.59
4.0	82.12	84.49	51.98
4.5	83.30	96.41	42.28
5.0	79.34	66.84	18.42

The comparative response can be adjusted by multiplying the error constant K_p. It is called the proportional gain constant. The gain constants obtained by optimizing the transfer function are given in Table 2 for various load currents.

PWM Converter: PWM will be used to control the quantity of power delivered to a load without undergoing the losses that would result from linear power delivery by resistive means. The potential drawbacks of this method are the switching frequency, pulsations defined by the duty cycle and properties of the load. With a sufficiently high switching frequency it reduces the usage of additional passive electronic filters, the pulse train can also be smoothed and average analog waveform gained.

High frequency PWM power control systems are easily realizable with semiconductor switches. As explicated, almost no power is dissipated by the switch in either on or off state. However, during the changeover between on and off states, both voltage and current are nonzero, thus power is dissipated in the switches. By rapidly changing the state between fully on and fully off, the power dissipation in the switches can be very low, compared to the power being delivered to the load [15].The frequency designed for the proposed PWM signal is 100 KHz. MOSFETs is well suited components for high efficiency controllers.

Control Technique: In conventional boost converter since the fixed parameters values are applied to PID controller, it allows the voltage raise during the transient period. They are designed to generate the voltage as constant across the load 24V in both the cases. It can be seen clearly in the conventional converter as the voltage rises up to 35V in transient period this factor is affecting the constant voltage load such as inverter and priciest DC loads. This factor is fully eliminated in proposed converter by using novel controller. And it functions with high efficiency.

Controlling of the main switch S_1 in the proposed converter is an important parameter. In order to control this in a successful manner the GA based PID controlled PWM signal is being generated and it is given to the main switch S_1 of the proposed converter as wave form shown in Fig.8. This wave form is varying its width of the pulses linearly with respect to the command received from the PID controller particularly to avoid the rising of the voltage not more than the reference voltage. And also the output voltage ripple factor is less, power consumption in the converter is also less and it is proven in simulation output. In addition to that, during the transient period to maintain the constant voltage it never raises the voltage more than the rated one so that the load equipment will not be affected by the over voltage. This is obviously shown in the output wave form obtained from the proposed one in Fig.9.

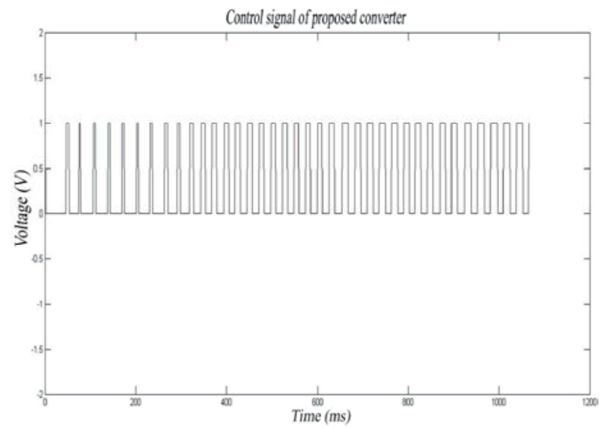

Fig. 8: Control signal in proposed converter

Simulation Results: From the simulation results in Fig.3 it is clear that the output wave form is raised in the conventional one more than the rated voltage what it is needed. In it, it is designed to make output 24V as constant during the transient period. But it rises up to the voltage range of 35V it will be hazardous to the precious load equipment. In order to avoid that in a successful manner the proposed converter is introduced. The main advantage of this converter is; it never allows the voltage rise more than the reference voltage what it needs. The load may be an inverter or any electrical apparatus, since it never damages any of the equipment in the case of transient or fluctuation in the speed of the wind turbine. The output wave achieved in the proposed converter has been shown in the Fig.9.

Table 3: Design specifications

Parameters	Values
V_{in}	10 V-21 V
V_{out}	24 V
L	80 μH
C	1.68 μF
fs	100KHz
RL	98 Ω

And one more advantage is, it has less power wastage in the converter. The proposed converter results are compared with conventional converter results for various loads. The result says that the proposed one is more efficient. It has been shown in Fig.10.

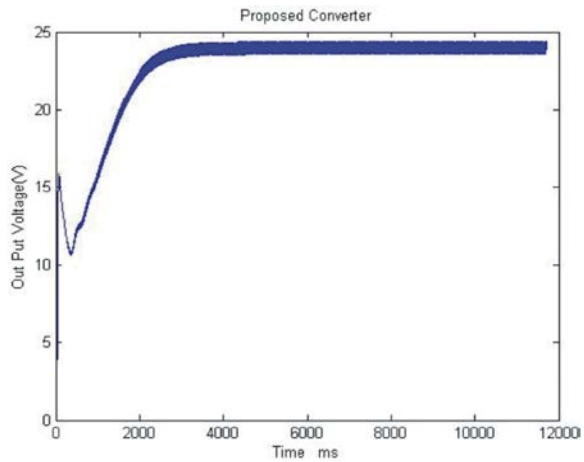

Fig. 9: Voltage wave form of the proposed converter

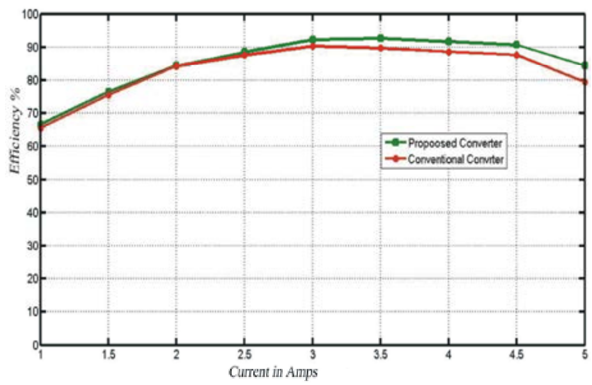

Fig. 10: Comparison of efficiency for various loads in both converters

Experimental Model: Hardware implementation has been done by using the single MOSFET model with PWM chip. The parameters used for the hardware implementation has been given in Table 3. The data obtained from GA optimization and PID controller is given as the input to PWM. Then the firing signal from PWM is given to the MOSFET switching device. The input supply for the boost converter is obtained from a small DC generator instead of DC wind generator with fluctuation. The output obtained from the converter is measured and monitored by cathode ray oscilloscope (CRO). The experimental setup is shown in the Fig.11. The control pulse and output result obtained from the model are shown in Fig.12 and Fig.13. As a final point the efficiency graph is plotted for various loads shown in fig.14.

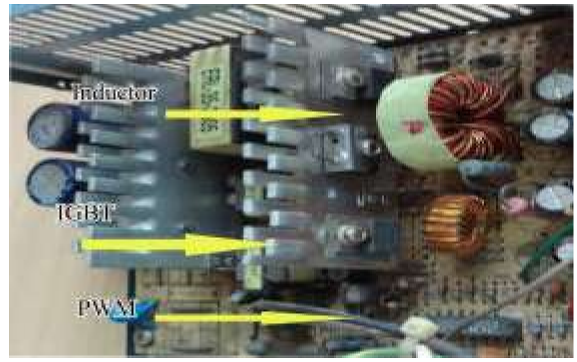

Fig. 11: Experimental Model of Proposed Converter

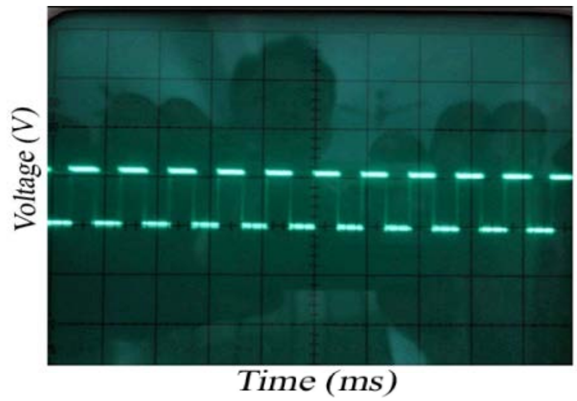

Fig. 12: Firing signal generated from PWM

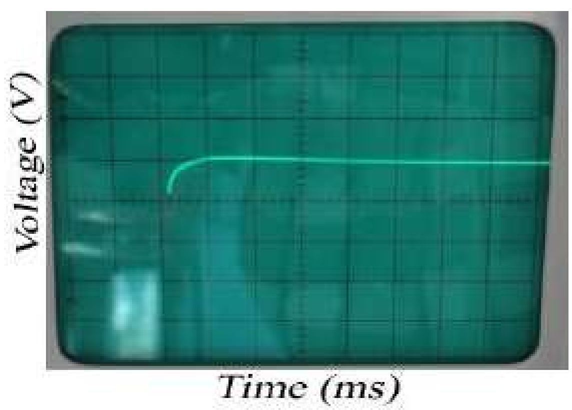

Fig. 13: Output obtained from proposed converter

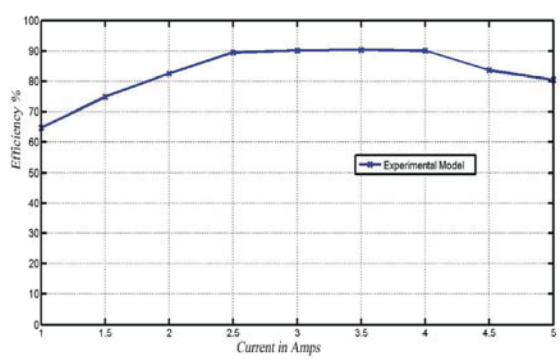

Fig. 14: Efficiency graph for experimental modal

And it is compared with the simulation results. Obviously, it shows better result similar to simulation results.

CONCLUSION

This proposed research work focuses a design consideration of the different parameters, an improved control strategy and very good experimental results. Many soft switched converter presented in the literature survey need large inductors and switching circuit. But in this proposed converter additional requirement needed is GA optimization for PID controller. In this converter MOSFET is used for the control switch because they are very sensitive for the high frequency application. The operating frequency of it is assigned by 100 KHz for both conventional and proposed method. By this proposed GA based PID controller PWM technique, the switching losses during transient period and power loss in the converter are reduced and very good voltage wave form is obtained. Due to the simple design, control technique and better efficiency it is well suited for applications like wind generators, battery vehicle and photovoltaic cells. Apart from that the proposed converter is identified as highly suited for breeze air DC wind generator system to enable the control voltage to a constant load, as well as into DC grid.

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