ASSESSMENT OF MFA CONTROL FOR RSC CONVERTER IN A GRID CONNECTED WECS

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Abstract

Wind energy system plays vital role in a non-conventional energy sources in India. In this paper an enhanced MFA controller is proposed to control RSC converter in a grid connected wind energy conversion system. Maximum Power Point Tracking is a significant control system in WECS to extract maximum energy from source and to regulate the converter voltage. In this paper Modified Firefly algorithm is proposed as MPPT in WECS. The MFA is a nature-inspired algorithm, which is the most powerful algorithm among optimization algorithms. DC/DC power converter control techniques are becoming trendier for satisfying the increasing challenges in the offshore wind power engineering. In this paper three stage high gain resonant switched capacitor DC/DC converter is proposed for high power WECS. The entire system is analysed using Matlab. The simulation analysis of proposed converter and control system are validated by experimental analysis.

Keywords: *Wind Energy Conversion System (WECS), Resonant Switched Capacitor (RSC), Permanent magnet synchronous generator (PMSG), Modified Firefly Algorithm (MFA).*

1. Introduction

The generation of electricity from renewable origins is the lack of dangerous releases and the unlimited existence of the prime mover that is influenced into electricity is the major advantage. The aerodynamic energy in the form of kinetic energy of the wind gets converted into electrical energy by a appropriate technical arrangement of a WT by in case of wind energy system [1]. The power of wind is a unidirectional origin by its nature; an unidirectional DC-DC converter can be utilized to associate the wind farm with the High Voltage DC (HVDC) terminal. In lots of converter topologies are improved for integrating with the electrical grid at currently [2]. The utilization of power electronic converters such as AC-DC converter and DC-DC converter allows for variable speed operation of the wind turbine, and increased power extraction [3]. For wind energy conversion system, the output power reduces as the wind speed decreases. The system needs more gain due to the decrease of input voltage, which is caused by wind speed reduction. For offshore wind energy systems a high-gain RSC DC/DC converter inaugurates to resolve the troubles [4]. In this analysis three stage resonant switched capacitor converter is proposed.

A control scheme aligned to get maximum power from the turbine and render regulated grid voltage and frequency is needed by in variable speed operation [5]. A wide range of control strategies, differentiating in cost and complexity, have been inquired for all the previously conceived conversion systems. All control schemes integrated with the power electronic converter are aligned to optimize power output at all potential wind speeds [6]. The traditional control objectives of a WECS are Maximum Power Point Tracking (MPPT), DC-link current and reactive power regulation. Control techniques are coordinated with the special concentrates on converter control. Various techniques have been analyzed for the wind to decide and track the MPPT, such as the perturb and observe [7,8], hill-climbing searching algorithm [9], fuzzy logic [7,10], artificial neural network [11], and neuro-fuzzy [12], Particle swarm optimization [13] and gradient approximation algorithm [14]. One of the new metaheuristic algorithms is the Firefly Algorithm for optimization problems which is established by Yang in 2008 [15]. FA is applied for MPPT in photovoltaic power system by various researchers. In this paper Modified Firefly algorithm is proposed to control high gain three stages resonant switched capacitor DC/DC converter control in WECS.

2. Wind Energy conversion system:

In this analysis WECS is designed with Permanent magnet synchronous generator (PMSG). Block diagram of proposed efficient WECS is shown in figure 1.

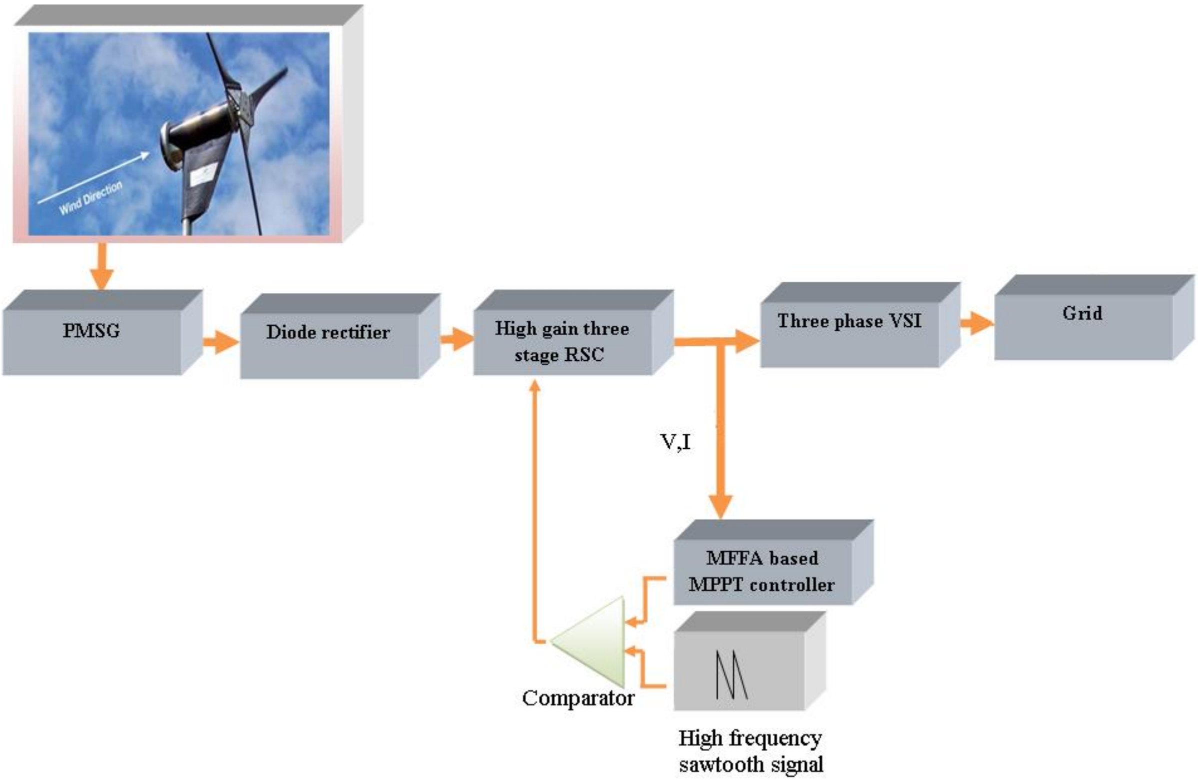

Figure 1 Block diagram of proposed WECS

The proposed WECS consists of wind turbine, PMSG, uncontrolled three phase diode rectifier, high gain three stages RSC and three phase voltage source inverter connected with the grid as depicted in figure 1. In this analysis PMSG is chosen due to their high efficiency, low losses, smaller size, less maintenance and high reliability.

2.1 Wind turbine:

The mechanical energy is produced with the help of wind turbine by converting the wind kinetic energy into mechanical energy. Horizontal Axis Wind Turbine (HAWT) is considered in this analysis for its high efficiency. The tip-speed ratio λ is given by:

$$\lambda=\omega_m R/v \qquad (1)$$

where *R is the* blade length (in m) and ω_m is the rotor speed (in rad/sec). Then, the output power of the wind-turbine is described as [16]:

$$P_{Turbine} = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v^3 \qquad (2)$$

where,ρis the air density (kg/m3), *R* is the blade radius (m), C_P is the performance coefficient of the turbine which is a function of the pitch angle of rotor blades β (in degrees) and *v* is the wind speed (in m/s). Any change in the wind velocity or the generator speed induces change in the tip speed ratio leading to power coefficient variation. Consequently, the extracted power is affected.

2.2 PMSG

The PMSG is engaged as the wind generator that converts the mechanical energy into the electrical energy. Here, the electrical torque (T_e) and the mechanical torque (T_m) are quoted in the succeeding equations (3) and (5),

$$T_e=P_m/\omega_r \qquad (3)$$

$$T_m = 0.5\times C_\rho V^3 \times \frac{60n}{2\pi n_g} \qquad (4)$$

Where, n is the gear box ratio, v is the wind velocity, n_g is the generator speed [17]. Three phase diode rectifier connected with the PMSG receives uncontrolled output voltage and rectifies into pure DC. The high gain three stages RSC DC-DC converter followed by rectifier regulates the voltage.

2.3 High gain three stage RSC converter:

Switched-capacitor (SC) DC/DC converters have concerned significant interest in the area of high power applications due to their high power density, high efficiency and simple control. The principle of the resonant switched capacitor cell based DC-DC converter is explicated in this section. Two modular cells are main parts of RSC converter which use a novel array of the diodes, solid-state switches, inductors and capacitors. Configuration of High gain three stage RSC converter is shown in figure 2.

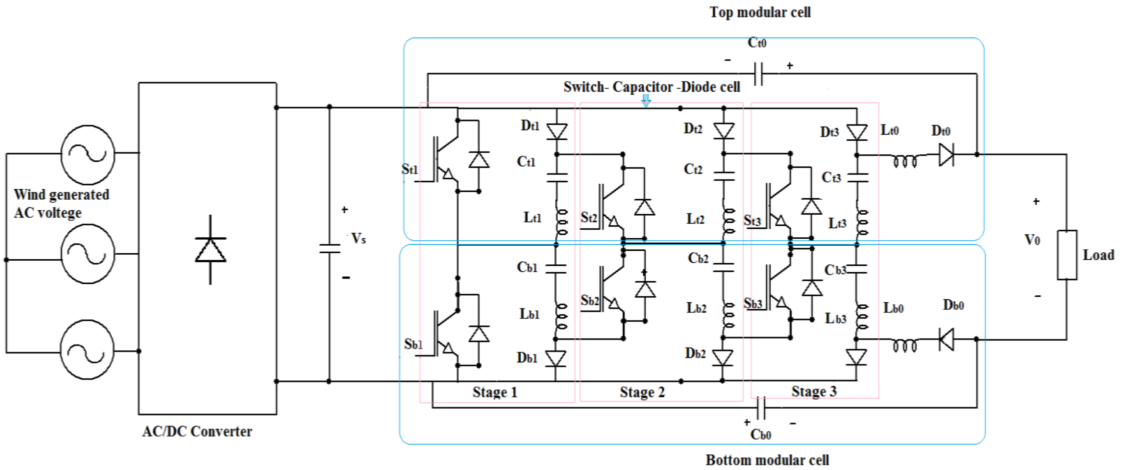

Figure 2 Configuration of High gain three stage RSC converter

The RSC converter is composed of six resonant capacitors (C_{t1}, C_{t2}, C_{t3}, C_{b1}, C_{b2}, C_{b3}) two output filter capacitors (C_{t0}, C_{b0}) six resonant inductors (L_{t1}, L_{t2}, L_{t3}, L_{b1}, L_{b2}, L_{b3}), six diodes (D_{t1}, D_{t2}, D_{t3}, D_{b1}, D_{b2}, D_{b3}) and six switches (S_{t1}, S_{t2}, S_{t3}, S_{b1}, S_{b2}, S_{b3}) .In this proposed model, subscripts of "t" and "b" stand for the equivalent variables to the components in the circuit at the top cell and bottom cell, respectively. The top module and bottom module switches are controlled with inverted pulses to reduce the conduction losses in the passive components and power devices. To simplify the analysis the subsequent assumptions are made [18]

- All the active and passive devices are ideal
- All the capacitors are equal rating and the inductances are equal
- To attain a zero-current switching the switching frequency is less than the resonant frequency

MODE *1*: In beginning of this mode 1, (S_{b1}, S_{b2}, S_{b3}) are turned on while (S_{t1}, S_{t2}, S_{t3}) are in off condition. The diodes (D_{b1}, D_{b2}, D_{b3}) are reverse biased. The charging currents flow through D_{t1}- S_{b1}- D_{t2}- S_{b2}- D_{t3}- S_{b3}. In the top cell, C_{t1}, C_{t2} and C_{t3} are charged, whereas C_{b1}, C_{b2} and C_{b3} are discharged to C_{b0} in the bottom cell. Before, C_{b1}, C_{b2} and C_{b3} were formerly charged at one and two times the input voltage level.

MODE 2: In the 2nd mode, all the active devices are in turned OFF condition. Consequently, the inductor currents are come to nil. The resonant capacitor (C_{t1}, C_{t2}, C_{t3}, C_{b1}, C_{b2}, C_{b3}) voltages are unchanged. The voltage of output capacitors (C_{t0}, C_{b0}) discharged to the load.

MODE *3:* (S_{t1}, S_{t2}, S_{t3}) are turned ON, while (S_{b1}, S_{b2}, S_{b3}) are OFF condition. The currents via top switches are raised by a function of soft-switching with the half-cycle resonant shape. In the 3rd mode (C_{t1}, $C_{t2,}$ and Ct3) are discharged to C_{t0}, whereas (C_{b1}, C_{b2}, C_{b3}) are charged through a phenomenon of resonant. In the mode 3, S_{t1}- L_{t1}- S_{t2}- L_{t2}- S_{t3}- L_{t3} - L_{t0}- D_{b0} is the path of current.

The RSC configuration output voltage will be sum of the output filter capacitor voltages and input voltages.

3. MFA Algorithm Based RSC converter control

MFA is applied as MPPT controller in the WECS. In the MFA the initial firefly population is determined randomly. The steps of MFA are

- First of all, all fireflies are unisex and will travel in the direction of the brighter and further attractive ones in anticipation of all of them have been compared (not including for itself).
- Secondly, the firefly attractiveness is connected to its brightness, which is based on the distance among itself and other flies. However, because of the light absorption of the air, the attractiveness decreases as the distance increases.
- At last, the light intensity or brightness of a firefly is estimated by the value of the objective function of a problem given.

The attractiveness can be quantitatively stated in (5).

$$B(r) = B_0 e^{-\gamma r_{ij}^2} \tag{5}$$

Where B_0 is the maximum brightness when $r = 0$; it is related to the value of the objective function, and a larger value means brighter. Here, γ is light absorption coefficient, and r_{ij} is the distance between the i^{th}, j^{th} fireflies. For any certain two populations of fireflies S_i and S_j, if $f(S_j) > f(S_i)$, move firefly i towards j based on the equation (6),

$$S_i^{t+1} = S_i^t + B(s_j^t - s_i^t) + a\varepsilon \tag{6}$$

Where, the second term is caused by the attraction, the third term is disturbance term which set for avoiding premature fall into local optimum. In a is a parameter controlling the step size and ε is a vector drawn from a Gaussian or other distribution. The aforesaid equation is random walk biased towards the brighter fireflies. If $B_0 = 0$, it will turn into simple random walk. For most execute, it may take $B_0 = 1, \alpha \in [0,1]$. The values of parameter γ are significantly vital in determining the speed of convergence. Flow chart of MFA is shown in figure 3.

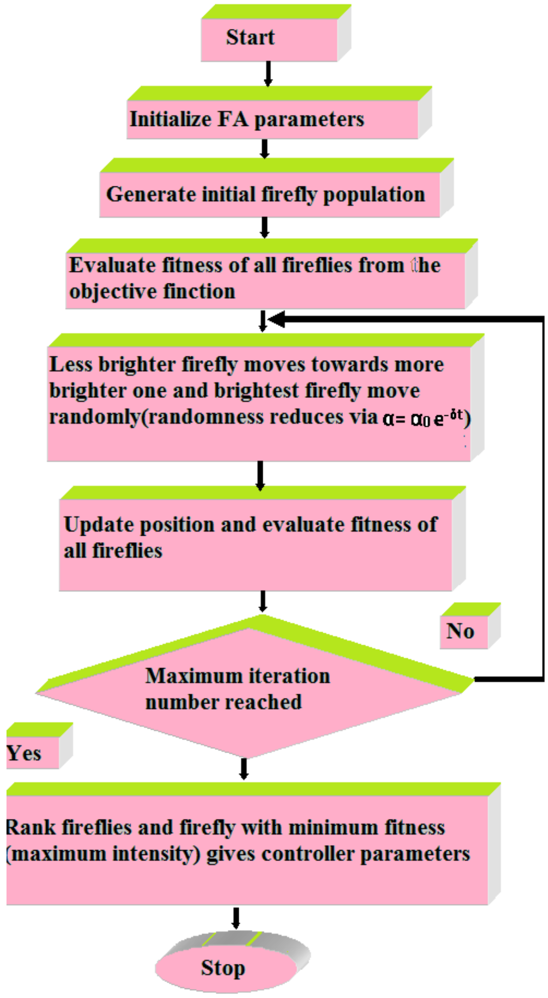

Figure 3 Flow chart of MFA

In the MFA for three stage RSC converter control firefly position is duty ratio, brightness stands for a power and brightness of the brightest firefly is the maximum power. The maximum power point is computed with the help of MFA algorithm and controls duty ratio of RSC converter. The voltage regulation of DC-DC converters plays significant role in power quality. The proposed algorithm is framed by four steps toward MPPT are stated as follows:

1) Step 1: initialization of parameters of the MFA, such as *α, β* and population size *N*. In the MFA, the duty cycle of DC-DC converter is mentioned as position of the firefly. In this paper, 5 numbers of fireflies are chosen.

2) Step 2: the position of firefly the corresponding wind output power. From wind output power the brightness of the firefly is attained.

3) Step 3: The firefly, which has greatest brightness, ruins in its position whereas the left over fireflies update their position.

4) Step 4: until the final iteration the optimization algorithm is operated.

The duty ratio produced from the algorithm is compared with high (resonant) frequency signal to produce triggering pulse for the upper module switches. Bottom module switches of RSC converter are triggered by the complementary pulses of upper switches. Therefore the output voltage of RSC converter is decided by the MFA. This MFA controlled voltage is fed to the three phase voltage source inverter where it is inverted into three phase AC to meet requirement of grid connection. The inverter output is connected with the grid.

4. Simulation Results and discussion

This section describes about the performance analysis of the proposed system with different wind speed condition. The proposed system is an MFA based RSC connected WECS, which gathered maximum power from the wind energy system. The Simulink model of the proposed system is illustrated in the figure 4.

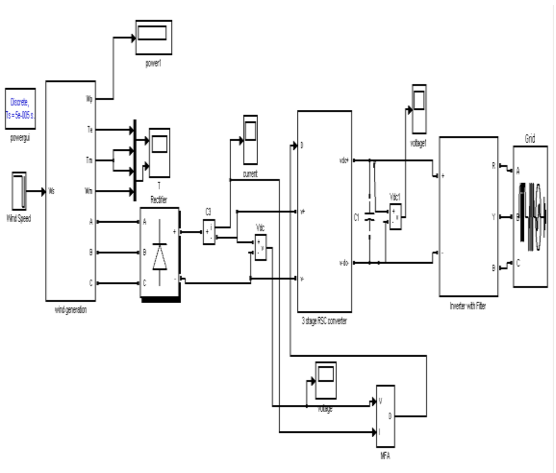

Figure 4 Simulink model of the proposed system

The proposed system is analyzed based on the 10 m/sec wind speed and the dynamic parameters are measured and illustrated. The wind speed, corresponding voltage, MFA controlled converter voltage, comparison of reference voltage with converter voltage and inverter output voltage for grid are shown in figure 5.

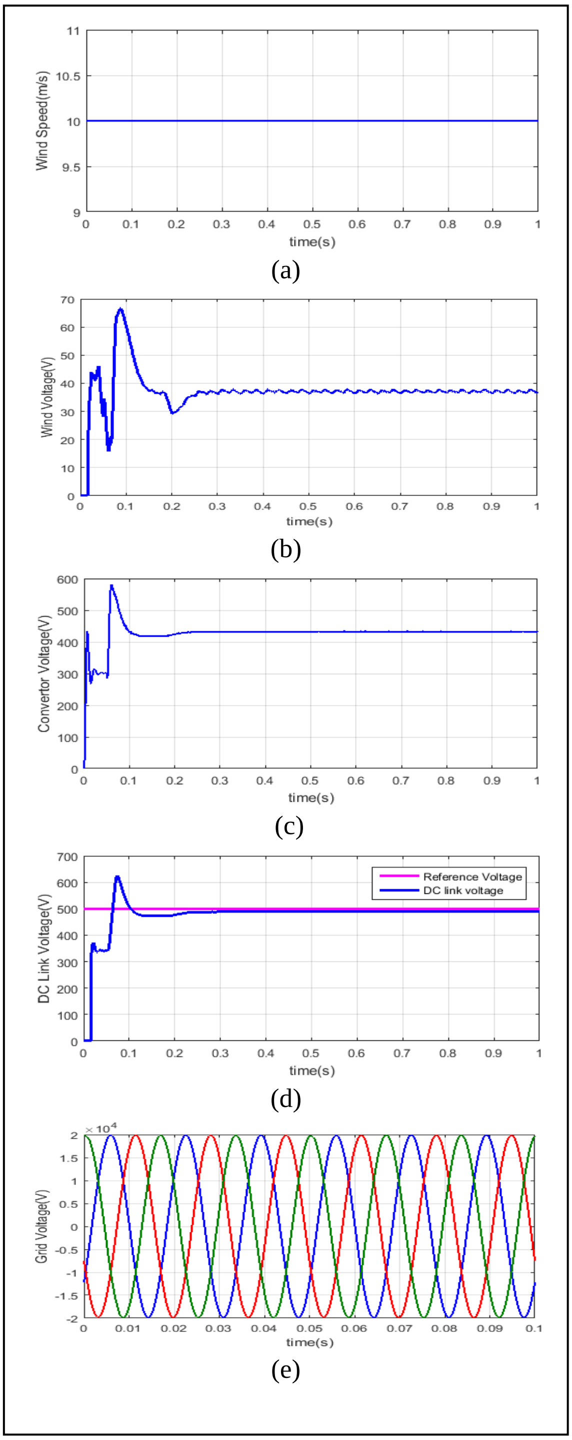

Figure 5 Performance of proposed system for 10m/sec wind speed

From the figure 5 it is noted that the grid current has some distortion in 0.05sec, that time the conventional MPPT algorithm is executed and then the proposed MFA is performed. The output voltage and current are given to the grid connected WECS, which maintains the stable output without any disturbance. Then the dynamic performance is evaluated with some speed variations, which is evaluated the 15m/sec wind speed. Figure 6 shows the performance of proposed system for 15m/sec wind speed.

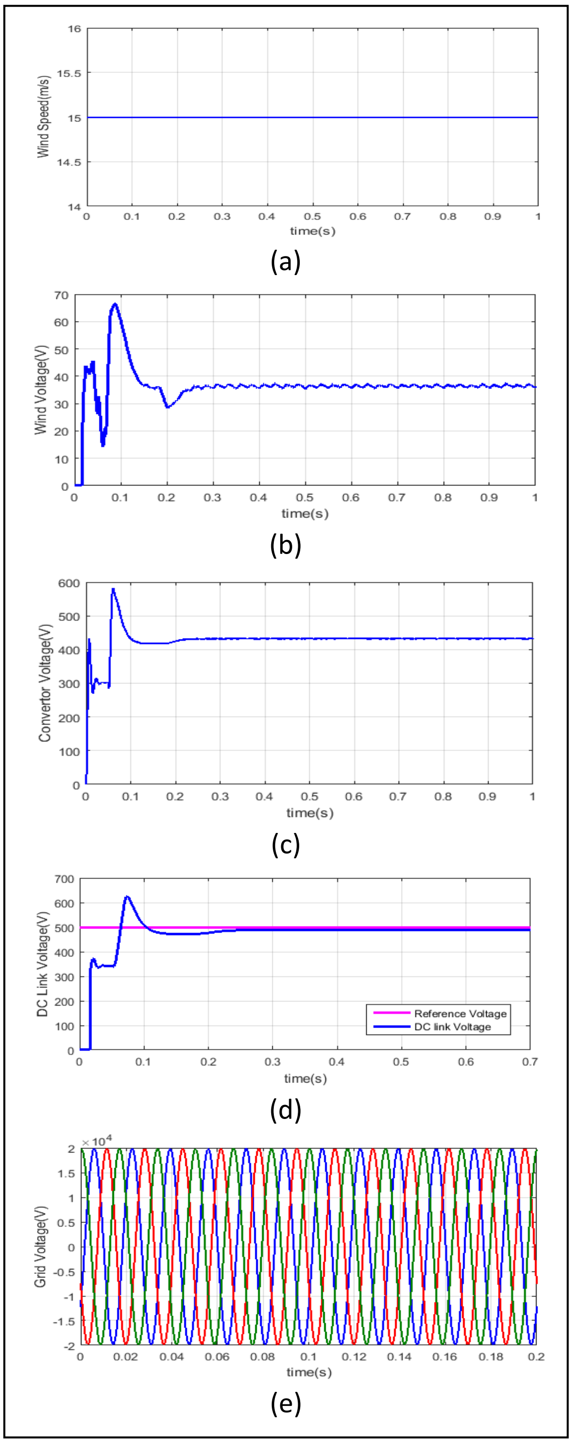

Figure 6 Performance of proposed system for 15m/sec wind speed

From the figure 6 it is noted that Wind voltage that is rectifier output is around 38V for a 15m/sec wind speed. The converter output voltage reaches the required DC voltage as shown in figure 6© with the help of high gain three stage RSC converter.

From the figure 5(d) and 6(d) it is clear that whatever the wind speed and converter input voltage, Proposed MFA algorithm effectively controls duty ratio of RSC converter and produces constant required voltage.

5. Experimental analysis:

For an experimental analysis wind energy system for 100w is considered. Wind energy system in the hardware consists of PMSG based wind generator, three phase diode rectifier with filter capacitor, high gain three stage RSC converter and DC load. 24V, 100w PMSG rated is connected in wind mill with the blade of 0.9m radius supported by pole of 3.2m. The maximum output voltage range of PMSG is 24V for maximum wind speed. The three stage RSC DC-DC converter is designed with 6 MOSFETS as switching devices with air core inductor for modules and filter. The Embedded controller of PIC16F887 is utilized here for implementation of MFA. Along with the programming of MFA PIC is programmed to measure the input, output voltage, current and to display the status of converter in 20*4 LCD.

Portrait of proposed system is shown in figure 7.

Figure 7 Portrait of proposed system

The figure 7 shows the entire arrangement of hardware such as wind mill, rectifier, three stage proposed RSC, Embedded based control system and lamp load. The power electronics unit alone is shown in figure 8.

Figure 8 power electronics unit of WECS

The power electronics unit consists of rectifier, three stage proposed RSC, Embedded based control system and lamp load. From the figure 8 it is noted that pulses produced by embedded controller for two modules of RSC are complementary as per discussion in section 2.3. Figure 9 shows the pulses produced and controlled output of converter by MFA for 20V input.

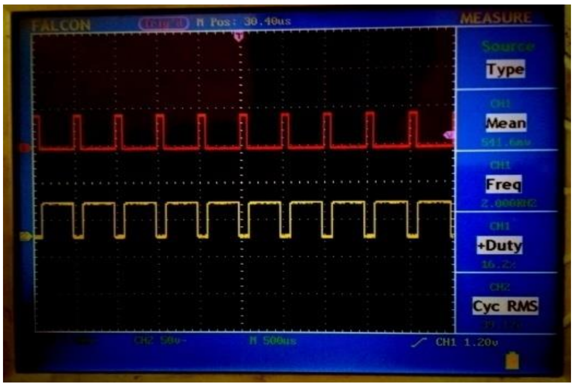

Figure 9 (a) Pulses by MFA for 20V input

Figure 9 (b) Voltage of RSC for 20V input

In figure 9 Performance of MFA for 20V input

From the figure 9(a) yellow wave is pulses for top modular switches and orange wave for bottom modular switches. Figure 9(b) yellow wave is output voltage and orange wave is input voltage. It is noted that input voltage 20V is boosted to desired 48V.

Figure 10 shows the pulses produced and controlled output of converter by MFA for 24V input.

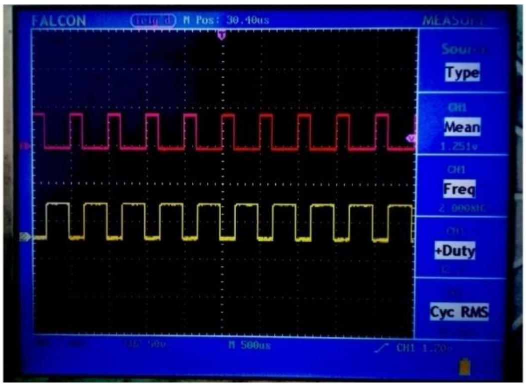

Figure 10 (a) Pulses by MFA for 24V input

Figure 10 (b) Voltage of RSC for 24V input

In figure 10 Performance of MFA for 24V input

From the figures 9 and 10 it is noted the pulse width is varied based on input voltage. Output is maintained constant at 48V by the effect of MFA even when the input voltage is varied by the effect of change in wind speed.

6. Conclusion:

In this paper enhanced high gain three stage resonant switched capacitor DC/DC converter is proposed for wind energy conversion system. An efficient nature-inspired Modified Firefly algorithm is proposed for MPPT in WECS which decides the duty ratio of RSC converter and regulates the voltage. For an analysis various wind speeds are considered to validate the performance of MFA and RSC converter. With the aid of resonant condition of the circuit the soft switching function is done. As a result, the switching losses are reduced in both ON and OFF time, and the system power density can be improved by raising the switching frequency. From the simulation results it is noted that MFA effectively controls the RSC converter and produces desired voltage irrespective wind speed and input voltage. From the analysis it is observed that high gain is achieved with the help of three stage RSC converter. The experimental analysis is done for 100w WECS with the DC load. Experimental results validate the effectiveness of controller in voltage regulation and tracking of maximum power.

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