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Novel Adaptive Controller for PMSG Driven Wind Turbine To Improve Power System Stability

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ABSTRACT*: This paper describes the behavior of a permanent magnet synchronous generator (PMSG) driven by wind turbine. The proposed conversion system is a good alternative due to its high efficiency and reliability. Electrolytic capacitors are not required in this type of converter and the voltage in the DC-link as well as the generated reactive power can be dynamically modified according to the wind velocity. The adaptive control strategy uses an adaptive PI which is self-tuned based on a linear approximation of the power system calculated at each sample time. Space vector technique for grid side inverter for transformer less integration of generator and a pulse-width modulated current source converter. A model reference is also projected in order to reduce the post-fault voltages. Simulation results prove the advantages of the proposed control. A MATLAB computer simulation study was undertaken and results on PWM-CSC are presented.*

Keywords*: Permanent Magnet Synchronous Generator (PMSG), Adaptive Controller, Space Vector Modulation (SVM)*

I. INTRODUCTION

Modern wind power applications require efficient and flexible technologies that adapt to changes in load and generation. In most of the wind turbines for on-land emplacements use double fed induction generators due to their economic advantages (i.e., high efficiency, improved controllability and reduced rating of the converter). Nevertheless, other energy conversion systems and generator technologies have been proposed recently[1].One of the most promising of them is the permanent magnet synchronous generator (PMSG) which has clear advantages in terms of efficiency and power density. Integration into the grid of this type of generators requires a full rated AC/AC converter which, in most cases, is based on the voltage source converter technology (VSC)[1]. Another possible type of converter is the pulse-width modulated current source converter (PWM-CSC) which has potentially more advantages for medium size wind turbines. It is capable of controlling the DC current according to the wind velocity independently of the DC voltage. This characteristic is exploited to create an adaptive control which does not require measure of the rotational speed. Adaptive control techniques that perform identification and control of dynamic systems can be adapted to highly-complex dynamic systems in order to auto-adjust the controller parameters .Similar to widely used SVM schemes for voltage source inverters, the SVM for CSI is also a digitally implemented vector synthesizing method [5].

A new adaptive control strategy for a wind energy conversion system based on a permanent magnet synchronous generator and a pulse-width modulated current source converter [3]. The proposed conversion system is a good alternative due to its high efficiency and reliability. The control strategy uses an adaptive PI which is self-tuned based on a linear approximation of the power system and a desired closed loop response[1][6].

II. ENERGY CONVERSION SYSTEM

The proposed energy conversion system is based on PMSG.This type of machine has three main features which are relevant for wind power applications: there are no significant losses generated in the rotor; magnetization provided by the permanent magnets allows soft start; and there is no consumption of reactive power. The first characteristic implies an improvement in efficiency while the second and third effect the power electronic converter which does not require bi-directional power capability [1][3]. Hence, a full bridge diode rectifier is enough for the AC/DC conversion. In addition, PMSGs allow smaller, flexible and lighter designs as well as lower maintenance and operating costs. A gear box is not required if it is designed appropriately with a high number of poles [1].PMSG based wind turbine is the most suitable scheme for electrical power generation and it overcomes the problem that exists in the conventional wind turbine power generation. The energy conversion in the conventional wind turbine driven induction generator is not satisfactory but the PMSG driven wind turbine is the most suitable scheme in terms of energy conversion efficiency. A new adaptive control strategy for a wind energy conversion system based on a permanent magnet synchronous generator and a pulse-width modulated current source converter [3].

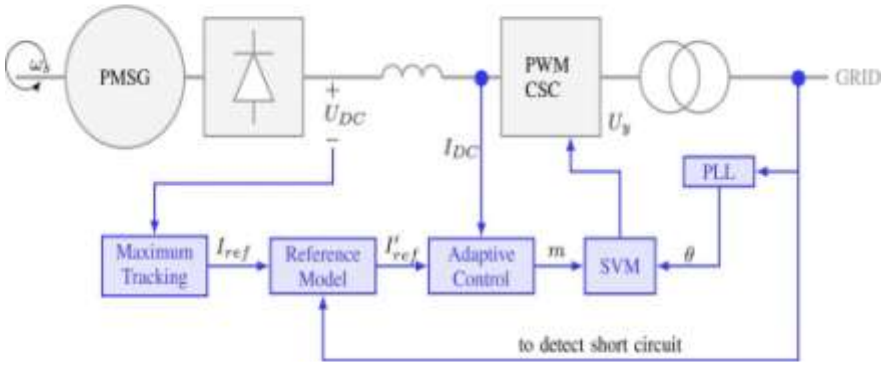

Fig.1: General Block Diagram of proposed system

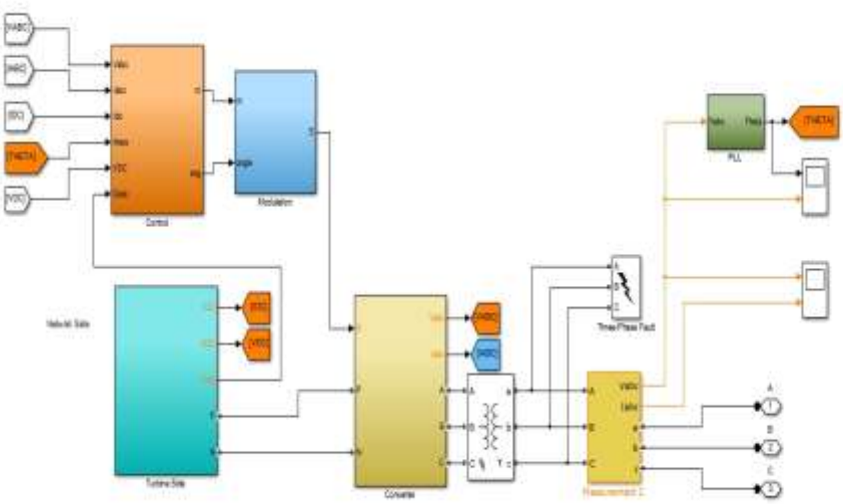

Fig.2: Schematic of proposed renewable based distributed generation system

The paper is so arranged in the order that: Section II describes the energy conversion system under consideration and the controller for grid-interfacing inverter. Section III includes a digital simulation study is presented. Section IV finally concludes the paper.

III. PROPOSED ADAPTIVE CONTROL FOR PWM-CSC

A hierarchical control is proposed for integration of the wind turbine into the grid as depicted in Fig. 4. First, the maximum tracking point algorithm is modified in terms of the DC current in the PWM-CSC. [5] Therefore, the reference for this current is modified dynamically according to the wind velocity. Next, an adaptive PI control is designed in order to track this reference. Finally, a model reference control is included in order to reduce the overvoltageresultingfromafaultinthegrid.Space vector modulation (SVM) is used to modulate the current of the converter [1][6].

3.1. Adaptive Control

This paper means by adaptive control any control strategy which uses parameter estimation of the plant in real time by using recursive identification.[1].The adaptive controller to be de- signed is based on the certainty equivalence principle: design the controller as long as the plant parameters are known. How- ever, since these are unknown at time, they are replaced by an estimate given by an online identifier [6]. This adaptive controller is easy to implement, since for the controlled plant, only the output signal is needed for feedback. An adaptive PI control is designed where the plant parameters are estimated by an online identifier, as shown in Fig.3.

In continuous time, a PI controller can be defined as

$$u(t)=k_p e(t)+k_i\int_0^t e(r)dr \qquad (1)$$

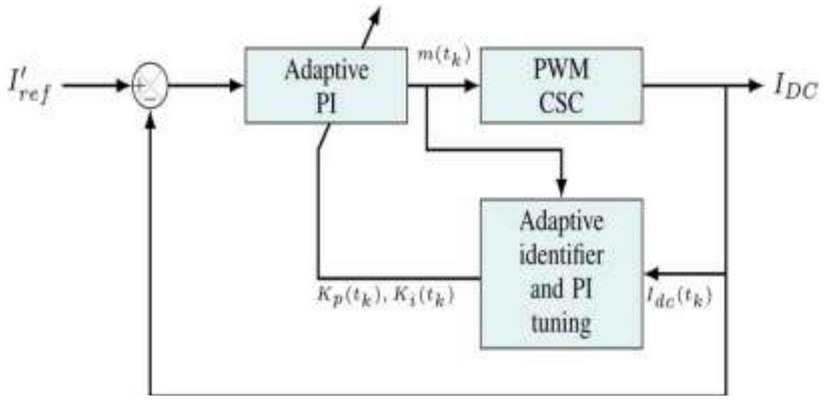

Fig.3: Adaptive control and identifier

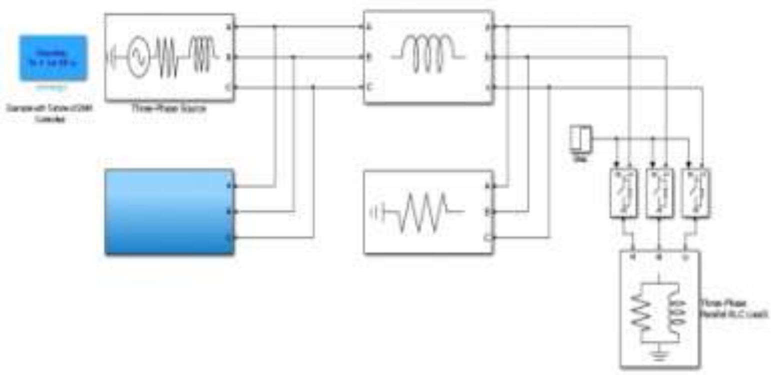

Fig.4: Simulation diagram representing the proposed energy conversion system connected to the grid

Being*u(t)* the control signal, and *e(t)* the error signal (represented by the difference between the reference and the output signals). In this case, these variables are given as follows [1]

$$e(t)=I'_{ref}(t)-I_{DC}(t) \qquad (2)$$

$$u(t)=-m(t).U_x(t).I_{DC}(t) \qquad (3)$$

In discrete time, the PI controller can be defined as

$$ei(t_k)=e_i(t_{k-1})+e(t_k) \qquad (4)$$

$$U(t_k)=K_P.e(t_k)+K_i.h_{ei}(t_k) \qquad (5)$$

Being the sample time $h=t_k-t_{k-1}$, $e(t_k)$and $e_i(t_k)$ the error and the integral error at time t_k respectively, and *ei(tk-1)* the integral error at time t_k*-1*. By defining a delay operator q^{-1}such as $y(t_k-1)=q^{-1}y(t_k)$. Equation can be rewritten as follows [1]

$$e_i(t_k)-e_i(t_{k-1})=e(k) \qquad (6)$$

$$(1-q^{-1}).e_i(t_k)=e(t_k) \qquad (7)$$

$$e_i(t_k)=\frac{1}{1-q^{-1}}.e(t_k) \qquad (8)$$

$$u(t_k) = k_p.e(t_k) + k_{ih}\frac{1}{1-q^{-1}}.e(t_k) \quad (9)$$

$$u(t_k) = (k_p + k_{ih}.\frac{1}{1-q^{-1}}).e(t_k) \quad (10)$$

$$u(t_k) = \frac{k_p(1-q^{-1}+k_{ih})}{1-q^{-1}}.e(t_k) \quad (11)$$

$$u(t_k) = \frac{k_p + k_{ih} - k_p.q^{-1}}{1-q^{-1}}.e(t_k) \quad (12)$$

Obtaining the following expression for the PI controller in discrete time

$$u(t_k) = \frac{c1 + c2.q^{-1}}{1-q^{-1}}.e(t_k) \quad (13)$$

where the parameters and of the PI controller in continuous time can be related to the controller in discrete time, as follows

$$k_p = -c2 \quad (14)$$

$$k_i = \frac{c1 + c2}{h} \quad (15)$$

Since the process to be identified is nonlinear, the identified model is a linear approximation of the nonlinear model at time instant t_k. A simplified first order model is selected, described by a discrete transfer function, as

$$y(t_k) = \frac{b_0^{\wedge}.q^{-1}}{1 + a_1^{\wedge}.q^{-1}}.u(t_k) \quad (16)$$

Equations by using the transformation as follows:

$$u(z) = \frac{c1 + c2.z^{-1}}{1 - z^{-1}}.E(z) = \frac{L(z)}{P(z)}.E(z) \quad (17)$$

and

$$y(z) = \frac{b_0^{\wedge}.z^{-1}}{1 + a_1^{\wedge}.z^{-1}}.u(z) = \frac{B(z)}{A(z)} \quad (18)$$

By using equations it is possible to formulate the block diagram

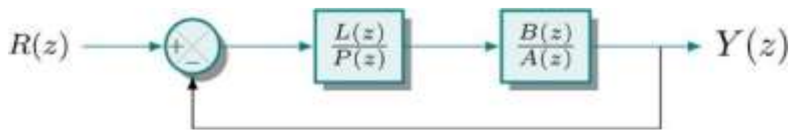

Fig.5: Diagram block using transformation

From this figure it is possible to obtain the closed loop transfer function, as follows:

$$y(z) = \frac{B(z)}{A(z)}.u(z) \quad (19)$$

$$u(z) = \frac{L(z)}{P(z)}.E(z) \quad (20)$$

$$E(z) = R(z) - y(z) \quad (21)$$

$$y(z) = \frac{B(z).L(z)}{A(z).P(z) + B(z).L(z)}.R(z) \quad (22)$$

If defining desired closed loop poles, given by

$$P_d\,(z) = (1-\alpha_1 z^{-1})\,(1-\alpha_2^{-2}) \quad (23)$$

where α_1 and α_2 are the discrete time roots of (34), which can be related to the continuous time roots $\alpha 1$ and $\alpha 2$ by using

$$\alpha 1 = e^{s_1 h} \quad (24)$$

$$\alpha 2 = e^{s_2 h} \quad (25)$$

It is possible to obtain the controller parameters by comparing the closed loop poles with the desired closed loop poles as follows:

$$p_d(z) = A(z).P(z) + B(z).L(z) \quad (26)$$

$$P_d(z) = (1 + a_1^\wedge.z^{-1})(1 - z^{-1}) + b_0^\wedge.z^{-1}(c_1 + c_2.z^{-1}) \quad (27)$$

$$p_d(z) = 1 - (1 - a_1^\wedge - b_0^\wedge.c_1)z^{-1} + (-a_1^\wedge + b_0^\wedge.c_2)z^{-2} \quad (28)$$

$$p_d(z) = 1 - (\alpha_1 + \alpha_2)z^{-1} + \alpha_1.\alpha_2.z^{-2} \quad (29)$$

Therefore, the controller parameters can be obtained as,

$$c_1 = \frac{(-\alpha_1 - \alpha_2 - a_1^\wedge + 1)}{b_0^\wedge} \quad (30)$$

$$c_2 = \frac{\alpha_1.\alpha_2 + a_1^\wedge}{b_0^\wedge} \quad (31)$$

Where it is evident that c_1 and c_2 are related to the linear approximation model of the nonlinear process, represented by the discrete transfer function. When the projection algorithm is applied in for the estimation the following actualization rule is obtained:

$$y^\wedge(t_k) = -a_1^\wedge.(t_k - 1).y(t_{k-1}) + b_0^\wedge(t_{k-1}).u(t_{k-1}) \quad (32)$$

$$a_1^\wedge(t_k) = a_1^\wedge(t_{k-1}) + \frac{-y(t_{k-1})}{y(t_{k-1})^2 + u(t_{k-1})^2}.(y(t_k) - y^\wedge(t_k)) \quad (33)$$

$$b_0^\wedge(t_k) = b_0^\wedge(t_{k-1}) + \frac{u(t_{k-1})}{y(t_{k-1})^2 + u(t_{k-1})^2}.(y(t_k) - y^\wedge(t_k)) \quad (34)$$

where $a_1(t_k)$ and $b_0'(t_k)$ are the estimated parameters at time t_k, and$a_1'(t_{k-1})$ and $b_0'(t_{k-1})$ are the estimated parameters at time t_{k-1}. Since the controller parameters are dependent on and according a_1' to b_0', a time varying parameters for each can be obtained as follows [1][6].

$$c_1(t_k) = \frac{(-\alpha_1 - \alpha_2 - \alpha_1^\wedge(t_k) + 1)}{b_0^\wedge(t_k)} \quad (35)$$

$$c_2(t_k) = \frac{(\alpha_1.\alpha_2 + a_1^{\wedge}(t_k))}{b_0^{\wedge}(t_k)} \quad (36)$$

where $c_1(t_k)$ and $c_2(t_k)$ are automatically tuned according to the desired closed loop poles.
Finally, the controller parameters K_P and K_I can be calculated by

$$k_p(t_k) = -c_2(t_k) \quad (37)$$

$$k_1(t_k) = \frac{c_1(t_k) + c_2(t_k)}{h} \quad (38)$$

Therefore, the resultant controller is an adaptive PI controller calculated for each t_k. The behavior of the controller can be determined by the selection of the desired closed loop poles and the sample time *h*.

3.2 Model Reference Adaptive Control

Reference current is modified during a short circuit in order to improve the short circuit behavior of the converter. A slightlydifferentcurrent inwhichthedesiredoutputisgen- erated by a linear reference model is proposed[1]. The reference model can be selected with an order less than or equal to the order of the process. In this work, a zero order model is used in prefault no control during the fault and a first order model after the fault as follows

$$I'_{ref} = H_m(z).I_{ref} \quad (39)$$

$$H_m(z) = \frac{(1-p_0).z^{-1}}{1-p_0.z^{-1}} \quad (40)$$

where ρ_0 must be selected as a stable root ($|\rho_0| < 1$), where it is clear that the reference model must be selected as a stable model with unitary gain. However, the selection of the reference model and the pole placement technique are separate problems, so it is evident that by using a reference model the flexibility of the control system in the assignment of the closed loop poles is increased. [1]The fault condition is detected using the voltage U_x.

IV. SIMULATION OUTPUT

To evaluate the maximum power extraction, DC link voltage control, grid voltage support control of a PMSG wind turbine the optimal control strategy has introduced, an integrated simulation of a complete PMSG system developed and detailed models in MATLAB Simulink in which both steady and variable wind conditions are considered[1][3]. In this chapter, obtained results are shown and discussed.

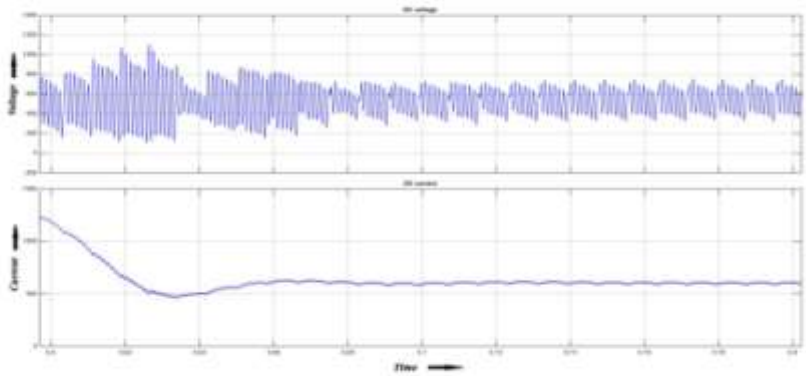

Fig.6: Output of DC Voltage and Current

The wind velocity provided to the system having 300 varying wind speeds for 0-15 sec output speeds. After the system is settled, the output power is very close to the maximum power that can be captured by the turbine at the wind speed. The rotor speed, electromagnetic torque, d-axis current, q-axis current and a single phase A is taken from produced three phase stator currents as shown in Fig.6. The rotor speed increases linearly as the rotor starts to rotate [4]. Electromagnetic torque produced by the PMSG is gradually decreased as shown in figure. d-axis and q-axis currents also decreased, finally the stator current (a) can be measured current in amps[1][3].

The control strategy changes dynamically according to the wind conditions as shown in Fig.8. If a time invariant PI control is used the performance could be similar at least at nominal wind velocity. In that case, the proposed algorithm can be used as a tuning technique.Three-phase voltages and currents in the PWM-CSC and the grid is same that are shown in Fig.9. Small harmonic distortions are present in three-phase voltages due to the commutation process. They are attenuated by the transformer and hence, the voltage in the point of common coupling is completely sinusoidal. A smoother waveform can be achieved by increasing the switching frequency at the expense of higher switching losses.

The system responses of the different control strategies are similar to those in Fig.7 Again, strategy control has the quickest responsesonthegrid-sideactive/reactivecurrents,whichisquite helpful to the voltage recovery of the utility. The output of modulation index (M), and DC current (Idc), Referencecurrent (Iref), TotalPower (p) are obtained which results are shown in fig.7

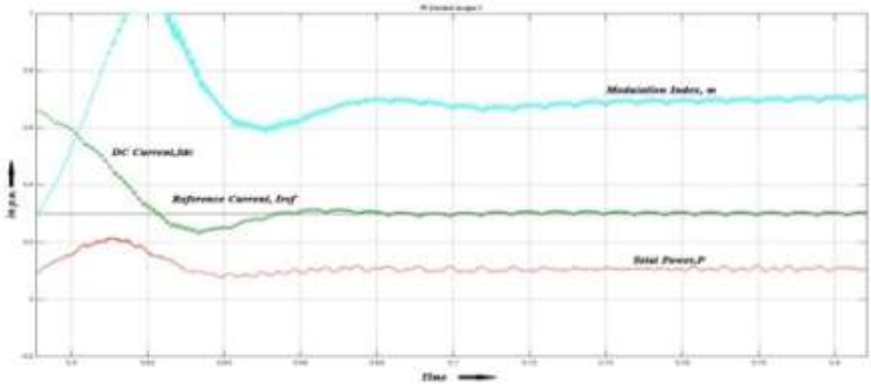

Fig.7: Output of Modulation Index(m), DC Current(Idc), Reference Current(Iref), Total Power(P)

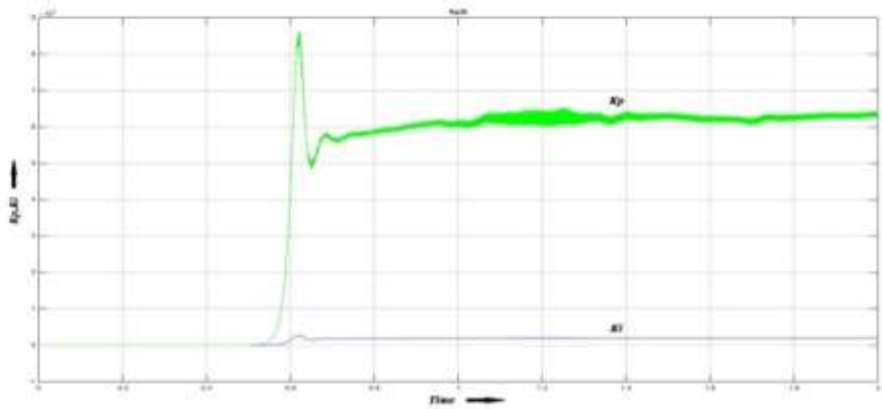

Fig.8: K_p, K_i characteristics

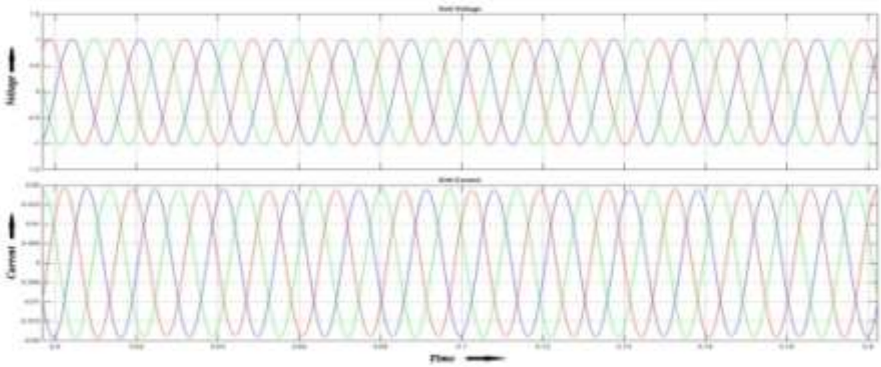

Fig.9: Output of Grid gives stable Voltage and Current

The generated 3 phase voltages, currents are shown in fig.9 ,which has similar operation as in PWM-CSC. In fig 10 the gererated output are selected and the THD present in them are shown. From this figure we can clearly say that the THD from the grid output.

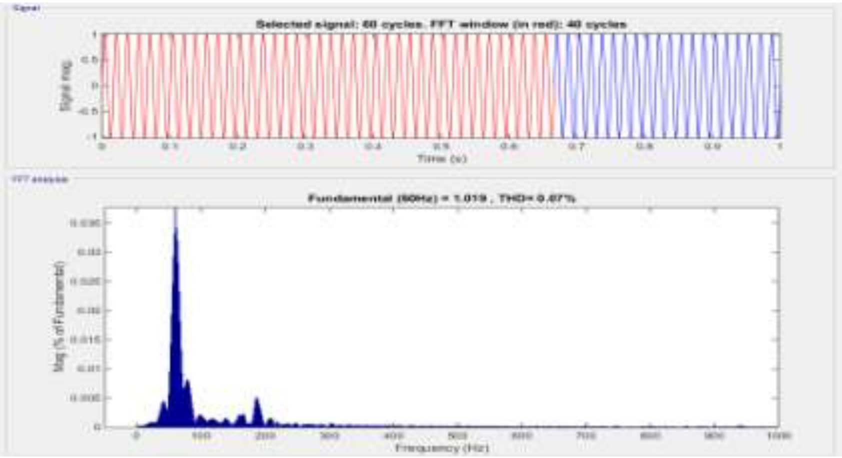

Fig.10: Output of Grid gives stable Voltage and Current

V. CONCLUSION

An adaptive control for a PWM-CSC-based energy conversion system mainly designed for wind power applications was presented. Both the control and the type of converter increase the flexibility of the wind turbine. They are able to operate in critical conditions such as short circuit and fast changes in wind velocity. Measurements of wind velocity or rotational speed are not required. A reference model is used to improve the transient behavior of the control after critical faults. For systems with time invariant behavior, the adaptive controller also behaves as a fixed controller. Therefore, it can be seen that the adaptive controller method can be used as a technique for self-tuning the controller based on the desired response.

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