An efficient hybrid reconfigurable wind gas turbine power management system using MPPT algorithm

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ABSTRACT

To improve power management scheme in standalone mode using hybrid wind-gas turbine system. To reduce electrical fluctuations due to permanent magnet synchronous generator (PMSG) in wind turbine system. For power generation, the wind turbine system is a main source. When there is reduction in wind turbine power generation, then gas turbine gets activated immediately and produces the required electricity in effective manner. This reconfigurable power generation system is controlled by perturb and observe maximum power point tracking (P&O_MPPT) algorithm. The proposed wind-gas power management system algorithm and device performance was analysed and simulated using MATLAB R2021a for various wind turbine experiment parameters. The simulation result shows that the proposed model and algorithm effectively meets the load demand when the wind turbine speed falls below the minimum required value.

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1. INTRODUCTION

Constant attempts and efforts are made to meet the increase in power demand over the years. Conventional sources of power have issues of reserves and pollution. Solar and wind energy are enormously available and can be efficiently utilized. Hybrid power generation units have become an integral part of the conventional grid in recent times [1], [2]. The foremost goals of HPSs' is such that to decrease zero power intermissions, lessen the price & deliver a consistent feed. The power system of wind utilized in our work comprises a diode which is a bridge rectifier and also a permanent magnet synchronous generator (PMSG), a wind turbine, a power-managed voltage source inverter a DC to DC boost converter. Resultant power which is generated from the PMSG is initially transformed to dc & after that, it is supplied to the grid. The transformations are accomplished at the factor of unity power & the voltage of dc-link is retained as fixed. Nevertheless, when speed of the wind drops lower than the minimum needed a minor gas turbine model is presented as a hold up or a backup source to sustain electricity of a nonstop stream mode [3]-[5]. The power of wind which is maximum is extracted from the wind power system controller and it supplies to the given grid with a worthy quality [6], [7]. A flow controller of power is utilized to maintain the supplied electricity from both sources of power. Mainly the request must be fulfilled by the power system of wind due to the ensuing benefits of the given environment. The surplus energy which comes through wind turbine shall be deposited in the electrolyze scheme. Once the speed of the wind is less than minimum, then there will be a gas-turbine system power which is supplemented sufficiently as per the requirement all through this situation [8], [9].

2. HYBRID RECONFIGURABLE WIND-GAS TURBINE POWER SYSTEM

This structure is a combination of a wind energy conversion scheme complemented alongside a gas turbine structure utilized in high & intermediate applications along with an electrolyze scheme for high applications and also for storing energy in an electrolyze system [10]. A blend of such kind of sources will actually assure an incessant power feed. The whole system diagram is depicted in Figure 1.

In these kind of hybrid amenities, the wind turbine precedence must be set [11], [12]. Once speed of the wind drops lower than the minimum needed, a regulating signal is directed towards the gas-turbine to instantly generate the anticipated electricity, The surplus energy which is generated through wind turbine shall be deposited in the electrolyze system. This shall be completed by the algorithm of power managing as shown in the flow diagram of Figure 2.

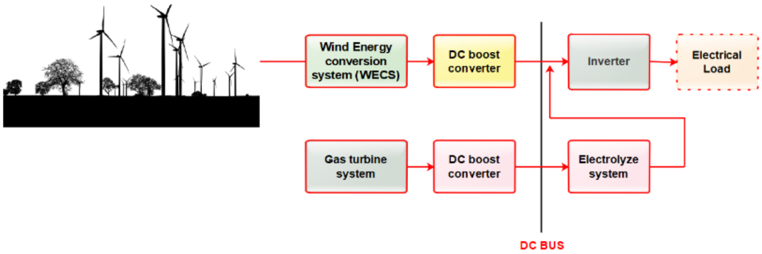


Figure 1. Functional block diagram of hybrid reconfigurable wind-gas turbine power system

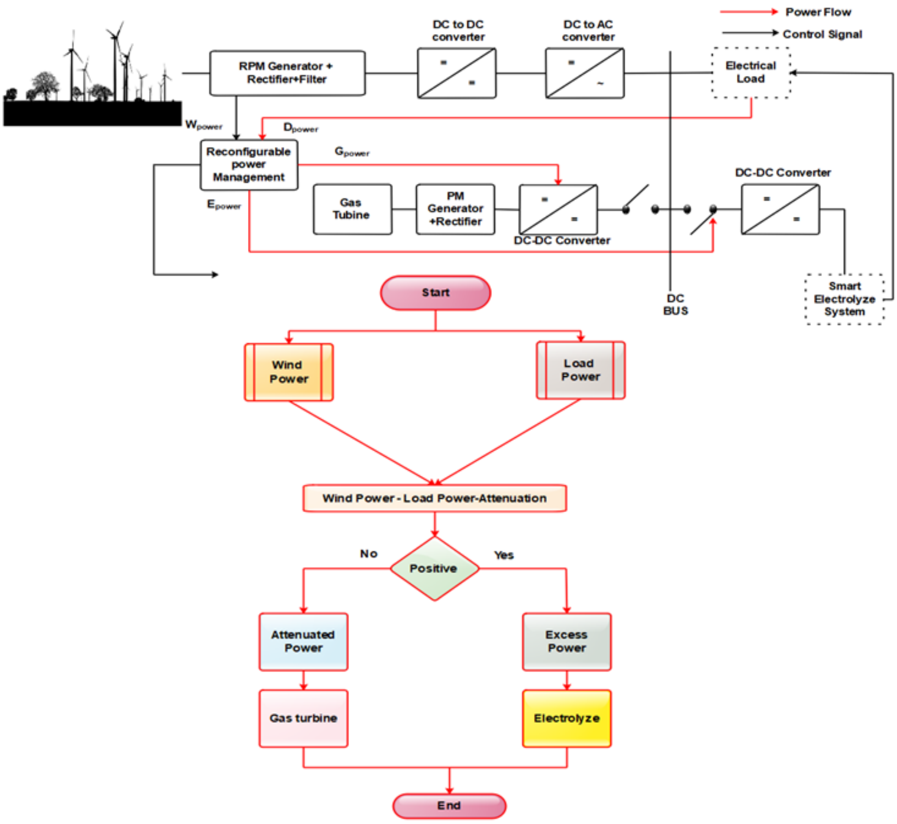


Figure 2. Proposed hybrid power management architecture

2.1. Conversion management scheme of wind turbine

Figure 1 shows the function block diagram of hybrid reconfigurable wind gas turbine power system. This scheme of wind generator is designed by a stable pitch wind turbine, a passive rectifier, a DC to DC voltage source inverter and parallely a gas turbine system which is connected to the wind turbine system to generate uninterrupted power supply to meet the load requirement.

2.2. Mathematical model of wind turbine system

The blades which are present on a wind turbine will mine the stream of energy from moving & supply it to the rotor of an electric generator through a gear box [13], [14]. The power of wind is calculated using (1).

$$P_w = \frac{1}{2}\beta D W_S^3 \tag{1}$$

Where, 'β' denotes the air density that differs with temperature & pressure of air. Here the P_c represents the power coefficient is generally specified as a function of the tip speed ratio, D presents the wind tubine blade rotating direction and ρ which is the pitch angle of blade [15], [16].
The angle which is amid the blade cross-section chord & plane of rotation is called the pitch angle. The tip speed ratio of a specified wind turbine is given in (2).

$$\gamma = \frac{t_v}{W_{S1}} = \frac{rA_r}{W_{S1}} \tag{2}$$

Where A_r is identified as angular velocity of the rotor, W_{s1} is described as wind speed, r is resperesented as radius of rotor in meters and t_v is described as blade pitch tangential velocity [17], [18].
For the wind turbine utilised here in our research work, P_c as a function of γ is specified through the (3) and (4).

$$P_c = 0.045 - 0.125\gamma + 0.156\gamma^2 - 0.072\gamma^3 + 0.015\gamma^4 - 0.0007\gamma^5 + 0.016\gamma^6 \tag{3}$$

The wind turbines output power (P_{wout}) is computed as given in (4).

$$P_{wout} = \frac{1}{2}P_c(\gamma)DW_s^3 \tag{4}$$

The rotor speed of the given generator versus mechanical power for various speeds of wind is depicted in Figure 2. The power which is obtained through the wind is actually maximized once P_c is at its maximum. This happens at a distinct value of the ratio of γ, tip speed. Therefore, for every speed of wind rotor speed is there which is optimum, such that maximum power is obtained through the wind. Hence in case speed of wind is presumed to be fixed, the value of P_c hinge on the speed of rotor of the wind turbine. So, power output of the turbine is regulated by regulating the rotor speed [19].

3. INTEGRATED PMSG BASED WIND TUBINE ELECTRICAL SYSTEM

The diagram of the integrated wind-gas turbine electrical system is depicted in Figure 3. The transformation of the wind power to the corresponding mechanical power in the given shaft of the rotor is done by the wind turbine. It is later transformed to electricity utilizing a PMSG. With the help of a 3-phase diode bridge rectifier, the output voltage is resolved. The converter of dc to dc is utilised to regulate the V_{dc} through capacitor C_1. The MPPT regulator supplies a voltage which is paralleled to the V_{dc} actual value. The outcome is supplied to a PI regulator, the output of which is paralleled to a triangular waveform in order to find at what time to make the dc dc boost converter switch OFF or ON [20]. The PWM inverter voltage source interacts with the scheme of wind turbine along with the power grid. It functions in a way that the amplitude of the output current differs so as to retain fixed V_0, the dc voltage through the C_0 capacitor [21].

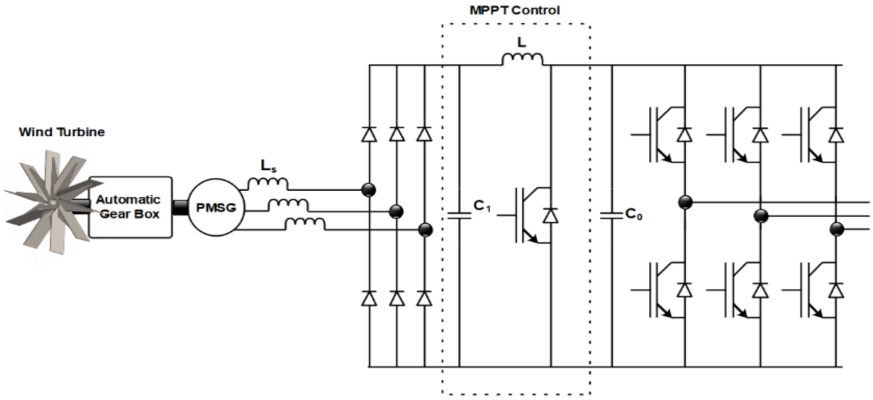


Figure 3. Integrated PMSG based wind energy conversion system (WECS)

3.1. Algorithm of maximum power tracking

Owing to its categorical features, the turbines of wind could be regulated to produce maximum power by means of search control approaches [22], [23]. Prior to understanding the maximum power tracing regulator, it is significant to know the fundamental physics of the structure. The mechanical power created is shown by (5).

$$P_m = T_m(s)A_R(s) \tag{5}$$

Where P_m is represents the mechanical power and T_m is identified as a mechincal torque, for ease, the produced electric power of a Solitary-phase generator is shown by (6).

$$P_{ele}(s) = V_g(s)I_g(s) \tag{6}$$

Where V_g is presented generated voltage and I_g is described as a generated current. Consider there is no attenuation in system, then the equation (6) can be represented as given in (7).

$$T_m(s).A_R(s) = V_g(s)I_g(s) \tag{7}$$

The fundamental electrical & motion equations are represents [8]-[11]:

$$T_{ele} = \tau I_g I_{fc} \tag{8}$$

$$I_g = \frac{V_g - E_g}{A_{res}} \tag{9}$$

$$E_g = \tau I_g A_{ele} \tag{10}$$

Where T_{ele} is identified as Electrical torque, I_{fc} is described as field current, E_g is represents as generated armature voltage , τ is described as torque nut factor, A_{ele} is represented electrical angular speed and A_{res} is identified as armature resistance. Electrical angular speed is given in (11).

$$A_{ele} = \frac{P}{2}A_R \tag{11}$$

Where p is the number poles of the generator. The resultant (12) obtained due to mean of (3) to (11).

$$P_{ele} = \frac{A_R \tau I_{fc}}{A_{res}}\,(V_g - \tau I_{fc}A_{ele}) \tag{12}$$

For a given diode rectifier,V_{dc}, the dc output voltage is relative to V , the generator phase voltage and (12) can be represented as given (13), therefore Maximum power generated at $\frac{dP_{ele}}{dV_{dc}} = 0$

$$P_{ele} = \frac{A_R \tau I_{fc}}{A_{res}}\,(V_{dc} - \tau I_{fc}A_{ele}) \tag{13}$$

From (13) it is perceived that the power mined through the wind could be regulated by differing the bus voltage of dc, that is normally a function of I_{fc} and A_{ele}. Seeing the features of wind turbine depicted in Figure 2, the maximum power point is got by the condition represented in (14)

$$\frac{dP_m}{dA_r} = 0 \tag{14}$$

Then 14 can be represented as shown in (15).

$$\frac{dP_m}{dA_R} = \frac{dP_m}{dV_{dc}} \frac{dV_{dc}}{dA_{ele}} \frac{dA_{ele}}{dA_R} = 0 \tag{15}$$

When maximum power point reached then (15) can be represented as represented in (16)

$$\frac{dp_m}{dV_{dc}} = 0 \tag{16}$$

The function $P_m(V_{dc})$ consists of a one point such that maximum power extraction is attained. This again implies that the supreme power could be traced by probing the corrected dc power, more than the situations of environment, like direction & speed of wind. The algorithm of MPPT is represent from (4) to (8). We can start the maximum power probing procedure by fixing a V_{ref}, which is the random dc side reference of voltage. The regulator will then process the voltage & dc side current, & computes the initial electric power $P_o = V_{dc}I_{dc}$. After this, the V_{ref} voltage reference is upsurged by ΔV_{dc} as given in 17.

$$V_{ref}(\tau) = V_{ref}(\tau - 1) + \Delta V_{dc} \tag{17}$$

The dc power is then computed with $P(\tau) = V_{dc}(\tau)I_{dc}(\tau)$
In case $P(\tau)$ is larger than $P(\tau - 1)$ that means the maximum power point hasn't stood touched hence, the voltage reference requires to be up surged by ΔV_{dc} & it requires the dc power to be paralleled. This procedure shall recur till maximum power is got. Also, in case $(\tau) < P(\tau - 1)$, The dc or the reference of voltage is further reduced by ΔV_{dc}.

4. INTEGRATED PMSG BASED GAS TURBINE ELECTRICAL SYSTEM

The rotor motion & non-stop power cycle of the gas turbine offers numerous benefits compared to other kinds of heat engines, along with moderately vibration less process. The one-shaft gas turbine has a fully integrated prime mover which is self-contained. This remarkably compact gas turbine has 3 fundamental phases: combustor, turbine & compressor [24]-[26]. In this work the gas system is reflected as apparatus providing electrical power at its output. Hence no subsequent particulars are given around it. Figure 2 depicts that a DC output which is variable in nature of the Wind turbine is interacted by a 450 V DC bus. The gas system power booster & WECS converters are given by (18), (19), (20), (21).

$$\frac{B_{vol}}{W_{vol}} = \frac{1}{1-\tau_W} \tag{18}$$

$$\frac{B_{vol}}{G_{vol}} = \frac{1}{1-\tau_G} \tag{19}$$

$$\tau_W = \theta_w * F_w \tag{20}$$

$$\tau_G = \theta_G * F_G \tag{21}$$

Where B_{vol} is represents voltage carried in a bus, $W_{vol}$is decribed the voltage generated by wind turbine, G_{vol} is identified as voltage generated by gas turbine, τ_w is represented as nut factor of wind tutbine, τ_G is nut factor of gas tutbine, θ is the chopping pulse width and f is the chopping frequency. Figure 4 depicts the Electrical circuit belonging to the DC to DC boost converter [27]-[29].

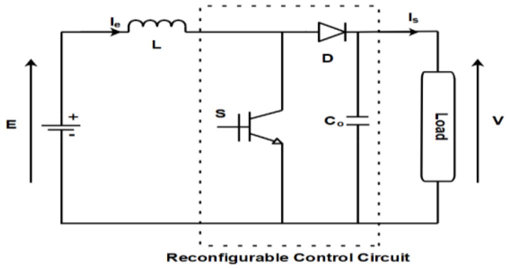


Figure 4. Reconfigurable DC power boost converter

5. THE POWER BALANCED ELECTROLYZE SYSTEM

This system is made up of the stacks of Electrolyze and a tank of hydrogen. As per faraday's law and considering account parasitic losses of current, the genuine hydrogen generation rate H_p (mol/s) of a stack of electrolyze is shwon in (22) [30]-[32].

$$H_p = \frac{\eta_F S_c I_{EZ}}{2F} \quad (22)$$

Where S_c number of series connected cells, I_{EZ} is the Electrolyzer input current (A), η_F is Faraday's efficiency and F is Faraday constant (C/kmol) [33]. Normally, in the tank there will be storage gases which are shown by the association amongst temperature, gas moles and pressure. The hydrogen tank's state of charge is estimated using (23).

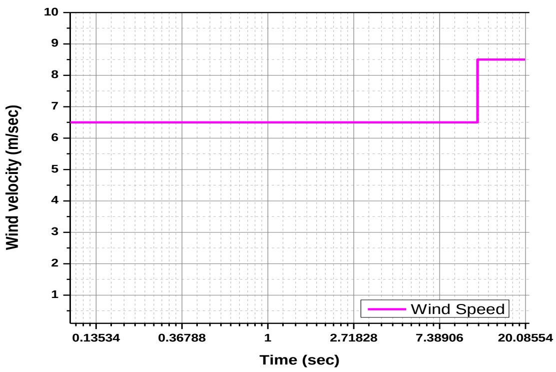
$$H_{soc}\% = \frac{\int (H_p - H_p^{in}) * 100}{S_{Hmax}} \quad (23)$$

Where S_{Hmax} is represented the maximum number of hydroges moles.

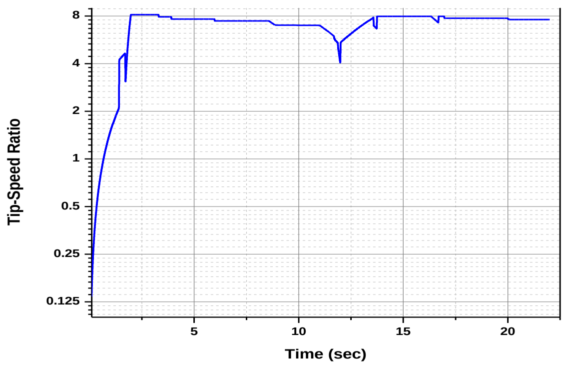
6. RESULTS AND DECUSSION

6.1. Simulation wind-gas MPPT results

The wind turbine summary is depicted in Figure 5 (a) and the output of simulation of the WECS with the given algorithm of MPPT are depicted in Figure 5 (b) and Figure 5 (c). We observe from that by the upsurge in the speed of the wind, the power supplied to the grid too upsurges that is shown by a raise in magnitude of PMSG phase current at Figure 5 (c). When t=12 s, the speed of wind is altered from 6 to 8 m/s in stage, however tip-speed ratio is sustained at Cp maximum in firm state circumstances as depicted in Figure 5 (b). It is observed that the regulator is competent to look for maximum power & retain the wind turbine power coefficient, near to its maximum.

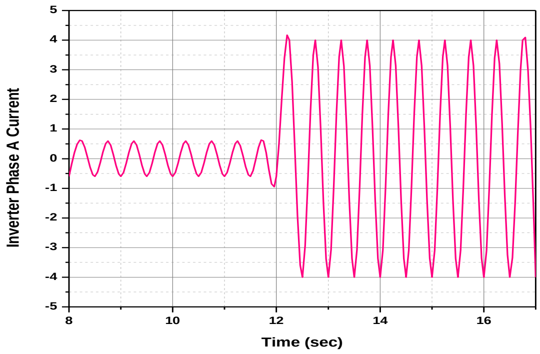


(a)



(b)

Figure 5. (a) Simulated analysis of wind turbine speed, (b) analysis wind turbine tip speed using MPPT algorithm



(c)

Figure 5. (c) analysis wind turbine inverter phase current using MPPT algorithm *(continue)*

6.2. Simulation results of hybrid reconfigurable power management system

The power maintenance flow diagram is shown by Figure 2. There was no consideration of the permanent magnet generator & the gas-turbine. The Rectifier group of the Turbine-Generator is modelled like a modest DC source which inserts the asked DC power inside the DC bus as depicted in Figure 2. The utilized profile of the speed of wind is represented in Figure 6. The equivalent attained power of wind turbine is depicted in Figure 7. Choose The load demand power profile is to be 2.6 kW with respect to the time varied in between 2 and 6 s, then 1.2 kW with respect to the time varied in between 6 and 10s, then 2.6 kW with respect to the time varied in between 9 and 14s & finally 1.6 kW for the balance simulation time as represented in Figure 8.

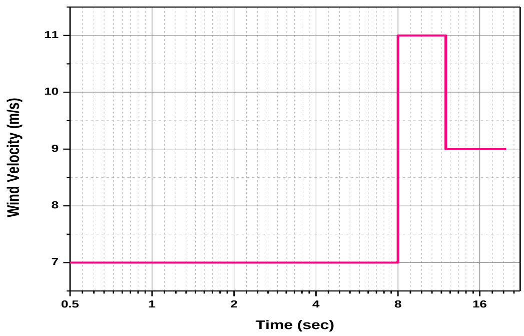


Figure 6. summary of wind speed profile

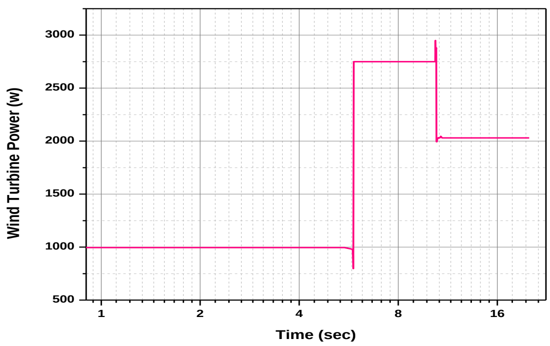


Figure 7. Summary of wind turbine power

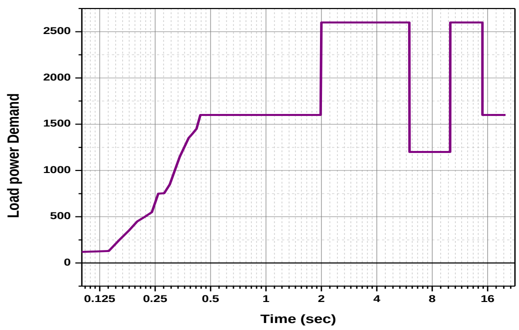


Figure 8. Summary of load power demand

The outcomes of simulation of the managing algorithm for diverse profiles of speed of wind are represented in Figure 9 and Figure 10 for the gas turbine and electrolyze system powers correspondingly. We notice seeing the graphs that among 2s and 6s, the power of wind turbine (1.2KW) is lesser than the load demand (2.6KW). The simulation of gas turbine is done by the difference (1.6KW) so as to balance the load. The similar mechanism is for the electrolyze system that is charging at 8s and 15s after the demand is lesser than the wind power. The opposite condition where it supplies power to the load isn't depicted. But the Electrolyze is favoured to the gas turbine till the deceasing of the power in the stacks.

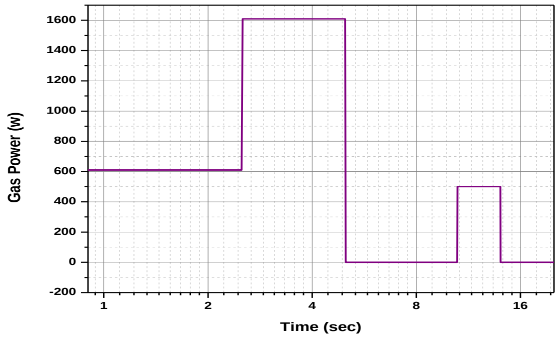


Figure 9. Gas tubine power execution summary

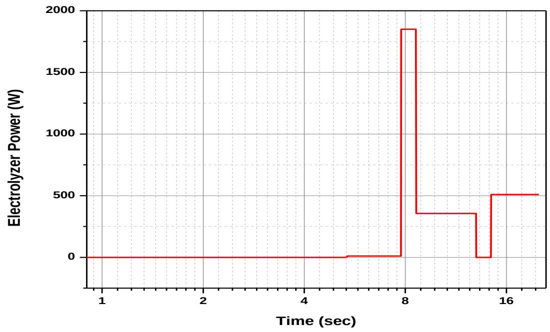


Figure 10. Electrolyze system power execution summary

7. CONCLUSION

The proposed method is implemented using hybrid reconfigurable wind and gas turbine model through P&O MPPT algorithm. The maximum power has been extracted from air stream for any given value of wind speed independent of wind or rotor speed by the proposed algorithm. This is validated by the analysis and simulation. It effectively generates the required power during low wind speed or rotor speed. The proposed hybrid power management scheme offers an efficient synchronization with wind turbine, gas turbine and electrolyze power system with respect to required load demand. Since wind energy is dilute and intermittent, to ensure reliable supply of demand, a gas turbine and an electrolyze system is incorporated to hybridize the system and controlled using power flow control techniques. For a hybrid power system, the proposed power flow control and management algorithm is found to be suitable through analysis and simulation results. The Scope for improvement can include investigations on the fuel-to-power efficiency of the gas turbine. For instance, judicial use of gas is possible by controlling the operating temperature, which makes the operation cost-effective.

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