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ACTIVE AND REACTIVE POWER FLOW OF ISOLATED WIND HYDRO HYBRID SYSTEM BY USING ADAPTIVE FILTER

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Abstract

This paper deals with a new isolated wind–hydro hybrid generation system employing one squirrel-cage induction generator (SCIG) driven by a variable-speed wind turbine and another SCIG driven by a constant-power hydro turbine feeding three-phase four-wire local loads.The proposed system consists of back-to-back-connected pulsewidth modulation controlled insulated-gate-bipolar-transistor-based voltage-source converters (VSCs) with a battery energy storage system at their dc link. The proposed wind-hydro hybrid system has a capability of bidirectional active- and reactive-power flow, by which it controls the magnitude and the frequency of the load voltage. The main objectives of the control algorithm for the VSCs are to achieve maximum power tracking (MPT) through rotor speed control of a wind-turbine-driven SCIG under varying wind speeds and control of the magnitude and the frequency of the load voltage.

Key words

Maximum power tractíng(MPT),Battery energy storage system(BESS),Squirrel cage induction generator(SCIG), Wind energy conversion system(WECS).

1. INTRODUCTION

The use of renewable energy sources, such as solar, wind and hydraulic energies, is very old; they have been used since many centuries before our time and their applications continued throughout history and until the "industrial revolution", at which time, due to the low price of petroleum, they were abandoned.During recent years, due to the increase in fossil fuel prices and the environmental problems caused by the use of conventional fuels,we are reverting back to renewable energy sources.Renewable energies are inexhaustible,clean and they can be used in a decentralised (they can be used in the same place as they are produced). Also,they have the additional advantage of being complimentary,the integration between them being favorable.

Wind power is extracted from air flow using wind turbines or sails to produce mechanical or electrical power.Windmills are used for their mechanical power, windpumps for water pumping, and sails to propel ships. Wind energy as an alternative to fossil fuels,is plentiful,renewable,widely distributed,clean,produces no green house gas emissions during operation and uses little land.The effects on the environment are generally less problematic than those from other power sources. Wind power is very consistent from year to year but has significant variation over shorter time scales. It is therefore used in conjunction with other sources to give a reliable supply. With the development of electric power, wind power found new applications in lighting buildings remote from centrally-generated power. Throughout the 20th century parallel paths developed small wind stations suitable for farms or residences, and larger utility-scale wind generators that could be connected to electricity grids for remote use of power. . The big advantage of hydro power is the water which the main stuff to produce electricity in is free, it not contain any type of pollution and after generated electricity the price of electricity is average not too much high. The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity. The average cost of electricity from a hydro station larger than 10 megawatts is 3 to 5 U.S. cents per kilowatt-hour. It is also a flexible source of electricity since the amount produced by the station can be changed up or down very quickly to adapt to changing energy demands. However, damming interrupts the flow of rivers and can harm local ecosystems, and building large dams and reservoirs often involves displacing people and wildlife.[1] Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower output level of the greenhouse gas carbon dioxide (CO_2) than fossil fuel powered energy plants[2].

A zigzag transformer is a special-purpose transformer with a zigzag or "interconnected star" winding connection, such that each output is the vector sum of two phases offset by 120°. Its applications are for the creation of a missing neutral

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connection from an ungrounded 3-phase system to permit the grounding of that neutral to an earth reference point and also harmonic mitigation, as it can suppress triplet (3rd, 9th, 15th, 21st, etc.) harmonic currents, to supply 3-phase power as an autotransformer (serving as the primary and secondary with no isolated circuits), and to supply non-standard phase-shifted 3-phase power. Nine-winding three-phase transformers typically have 3 primaries and 6 identical secondary windings, which can be used in zigzag winding connection as pictured. As with the conventional delta or wye winding configuration three-phase transformer, a standard stand-alone transformer containing only six windings on three cores can also be used in zigzag winding connection, such transformer sometimes being referred to as a zigzag bank[1].In all cases, six or nine winding, the first coil on each zigzag winding core is connected contrariwise to the second coil on the next core. The second coils are then all tied together to form the neutral, and the phases are connected to the primary coils. Each phase, therefore, couples with each other phase, and the voltages cancel out. As such, there would be negligible current through the neutral point, which can be tied to ground. RC circuits can be used to filter a signal by blocking certain frequencies and passing others. The inductor's impedance increases with increasing frequency[3]. This high impedance in series tends to block high-frequency signals from getting to the load.

For the hybrid system, a new control algorithm is proposed that has the capability of MPT, harmonic elimination, load leveling, load balancing, and neutral current compensation along with VFC. The objectives of the machine (SCIG*w*) side converter are to provide the requisite magnetizing current to the SCIG*w* and to achieve MPT. In the conventional control of variable-speed SCIGs, the objective of the load-side converter (called as grid-side converter in the grid-connected systems) is to maintain the dc-bus voltage constant at the dc link of two back-to-back connected VSCs. Because in the proposed system the dc-bus voltage is kept constant by the battery, the control objective of the load-side converter is different, i.e., to maintain an active power balance in the system by transferring the excess power to the battery or for providing deficit power from the battery. Further, the load-side converter provides the requisite reactive power for the load. The reactive-power requirement of the SCIG*h* is provided by the excitation capacitors connected at its stator terminals.

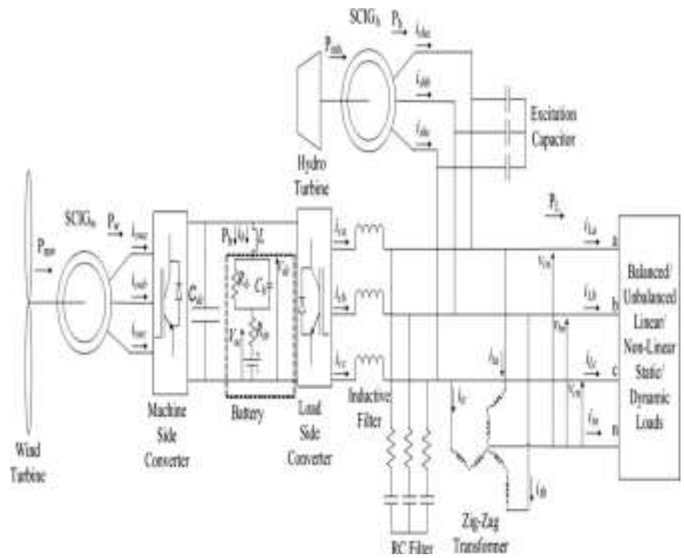

Fig1.Schematic diagram of wind hydro hybrid system

2. PRINCIPLE OF OPERATION

For the proposed system, there are three modes of operation. In the first mode, the required active power of the load is less than the power generated by the SCIG*h*, and the excess power generated by the SCIG*h* is transferred to the BESS through the load-side converter[4]. Moreover, the power generated by the SCIG*w* is transferred to the BESS. In the second mode, the required active power of the load is more than the power generated by the SCIG*h* but less than the total power generated by SCIG*w* and SCIG*h*. Thus, portion of the power generated by SCIG*w* is supplied to the load through the load-side converter and remaining power is stored in BESS. In the third mode, the required active power of the load is more than the total power generated by SCIG*w* and SCIG*h*. Thus, the deficit power is supplied by the BESS, and the power generated by SCIG*w* and the deficit met by BESS are supplied to the load through the load-side converter.

As the wind speed varies, the rotor-speed set point changes, and the difference in the reference rotor speed and the sensed rotor speed is fed to the controller for the machine (SCIG*w*) side converter, also referred to as the speed controller. The load-side converter is controlled for the regulation of load-voltage magnitude and load frequency. Further, for maintaining the load-frequency constant, it is also essential that any surplus active power in the system is diverted to the battery[5]. Alternatively, the battery system should be able to supply any deficit in the generated power. Similarly, the magnitude of the load voltage is maintained constant in the system by balancing the reactive-power requirement of the load through the loadside converter.

In the proposed algorithm, the rotor position (θ_{rw}) of SCIG*w* and the wind speed are sensed. The rotor speed (w_{rw}) of SCIG*w* is determined from its rotor position (θ_{rw}) The tip speed ratio (λ_w) for a wind turbine of radius *rw* and gear ratio *ηw* at a wind speed of *Vw* is defined as

$$\lambda_w = \frac{w_{rw} r_w}{\eta_w V_w} \qquad (1)$$

For MPT in the wind-turbine-generator system, the SCIG*w* should operate at the optimum tip speed ratio (λ^*_w) as shown in Fig. 2. Thus, the reference rotor speed w^*_{rw} for MPT is generated using (1) as

$$w^*_{rw} = \lambda^*_w V_w \, {}^{\eta_w}/_{r_w} \qquad (2)$$

The reference rotor speed of SCIG*w* is compared with w_{rw} to calculate the rotor-speed error (w_{rwer}) at the *n*th sampling instant as

$$w_{rwer(n)} = w^*_{rw(n)} - w_{rw(n)} \qquad (3)$$

The aforementioned error is fed to the speed proportional integral (PI) controller[5].At the *n*th sampling instant, the output of the speed PI controller with proportional gain *Kpω* and integral gain *Kiω* gives the reference *q*-axis SCIG*w* stator current (*I∗ qsw*) as

$$I^*_{qsw(n)} = I_{qsw(n-1)} + K_{pw}\left(w_{rwer(n)} - w_{rwer(n-1)}\right) + K_{iw} w_{rwer(n)} \qquad (4)$$

The reference *d*-axis SCIG*w* stator current (I*dsw) is determined from the rotor flux set point ()at the *n*th sampling instant as

$$I^*_{dsw(n)} = {}^{\emptyset^*_{drw}}/_{L_{mw}} \qquad (5)$$

For generation of three-phase reference SCIG*w* stator currents (*i**swa*,*i**swb*, and *i**swc*), the transformation angle *θ*rotorflux*w* is generated as (Fig. 4)

$$\theta_{rotorfluxw} = \theta_{slipw} + \left(\frac{p_w}{2}\right)\theta_{rw} \qquad (6)$$

where *θ*slip*w* is the slip angle,which is generated by integrating the slip frequency (*ω*slip*w*) as

$$\theta_{slipw(n)} = \int w_{slipw(n)}\, dt \qquad (7)$$

*ω*slip*w* at the *n*th sampling instant is generated as

$$w_{slipw(n)} = \left(R_{rw} I^*_{qsw(n)}\right)/\left(L_{rw} I^*_{dsw(n)}\right) \qquad (8)$$

The three-phase reference SCIG*w* stator currents (*i**swa*, *i**swb*,and *i**swc*) are then compared with the sensed SCIG*w* stator currents (*iswa*, *iswb*, and *iswc*) to compute the SCIG*w* statorcurrent errors, and these current errors are amplified with gain (*K* = 5) and the amplified signals are compared with a fixedfrequency (10 kHz) triangular carrier wave of unity amplitude to generate gating signals for the IGBTs of the machine-side VSC [6]. The sampling time of the controller is taken as 50 *μ*s, as this time is sufficient for completion of calculations in a typical DSP controller.Selection of Specifications of Wind Turbine and Gear Ratio.The wind turbine is designed for 55 kW at 11.2 m/s, which is considered as rated wind speed. For wind speeds below the rated wind speed, the mechanical power *Pm* captured by the turbine is a function of wind speed *Vw*, radius of turbine *rw*,density of air *ρ*, and coefficient of performance *Cp*, and is given as

$$P_m = 0.5 C_p \pi r^2 \rho V_w^3 \qquad (9)$$

An **adaptive filter** is a system with a linear filter that has a transfer function controlled by variable parameters and a means to adjust those parameters according to anoptimization algorithm. Because of the complexity of the optimization algorithms, most adaptive filters are digital filters. Adaptive filters are required for some applications because some parameters of the desired processing operation (for instance, the locations of reflective surfaces in a reverberant space) are not known in advance or are changing. The closed loop adaptive filter uses feedback in the form of an error signal to refine its transfer function.

Generally speaking, the closed loop adaptive process involves the use of a cost function, which is a criterion for optimum performance of the filter, to feed an algorithm, which determines how to modify filter transfer function to minimize the cost on the next iteration. The most common cost function is the mean square of the error signal. As the power of digital signal processors has increased, adaptive filters have become much more common and are now routinely used in devices such as mobile phones and other communication devices, camcorders and digital cameras, and medical monitoring equipment.

The idea behind a closed loop adaptive filter is that a variable filter is adjusted until the error (the difference between the filter output and the desired signal) is minimized. The Least Mean Squares (LMS) filter and the Recursive Least Squares (RLS) filter are types of adaptive filter. There are two input signals to the adaptive filter: d_k and x_k which are sometimes called the primary input and the reference input respectively

d_k which includes the desired signal plus undesired interference and

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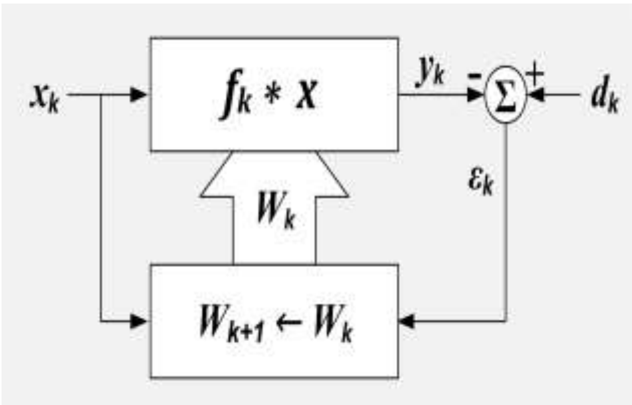
x_k which includes the signals that are correlated to some of the undesired interference in d_k.
k represents the discrete sample number.



Adaptive Filter. k = sample number, x = reference input, X = set of recent values of x, d = desired input, W = set of filter coefficients, ε = error output, f = filter impulse response, * = convolution, Σ = summation, upper box=linear filter, lower box=adaption algorithm

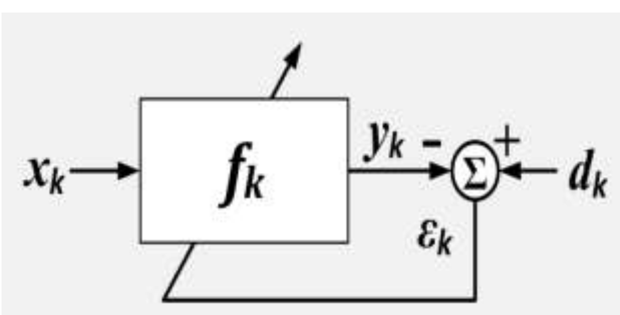
The filter is controlled by a set of L+1 coefficients or weights.

$$W_k = [w_{0k}, w_{1k}, w_{2k} \ldots, w_{Lk}]^T$$

It represents the set or vector of weights, which control the filter at sample time k. where w_{lk} refers to the *l*th weight at k'th time.

ΔW_k represents the change in the weights that occurs as a result of adjustments computed at sample time k.

These changes will be applied after sample time k and before they are used at sample time k+1. The output is usually ϵ_k but it could be y_k or it could even be the filter coefficients.



Adaptive Filter, compact representation. k = sample number, x = reference input, d = desired input, ε = error output, f = filter impulse response, Σ = summation, box=linear filter and adaption algorithm.

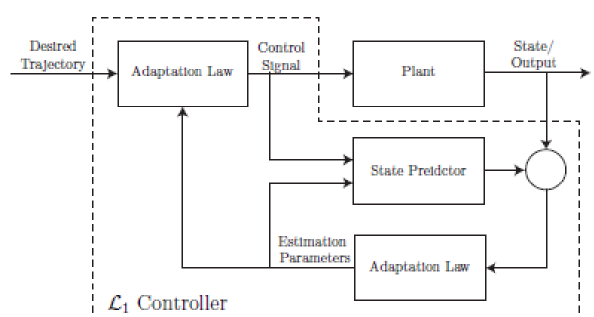
The input signals are defined as follows:

$$d_k = g_k + u_k + v_k$$
$$x_k = g'_k + u'_k + v'_k$$

where:

g = the desired signal,
g' = a signal that is correlated with the desired signal *g* ,
u = an undesired signal that is added to *g* , but not correlated with *g* or *g'*
u' = a signal that is correlated with the undesired signal *u* ,but not correlated with *g* or *g'* ,
v = an undesired signal (typically random noise) not correlated with *g* , *g'* , *u*, *u'* or *v'* ,
v' = an undesired signal (typically random noise) not correlated with *g* , *g'* , *u*, *u'* or *v*.

A good controller needs to be able to counter those uncertainties. Adaptive control is used for controlling such plants with uncertainties. Although, the objective is often not to have perfect estimation.
Rather it is to get; what may be a non-accurate estimate of uncertainties; albeit one that makes the overall system behave well. Model Reference Adaptive Control (MRAC) has been shown to have good features in terms of performance . For example, MRAC that ensure arbitrarily close performance to the desired dynamics have been developed . For MRAC, fast adaptation is often required to ensure close to desired performance.
L1 control addresses this robustness problem by decoupling it with adaptation rate [8]. Therefore, for an L1 controller, adaptation rate can be set arbitrarily high, whereas, robustness is ensured by adding a low pass _lter to the controller. At the end, L1 control guarantees bounds on transient performance while providing guaranteed robustness. This makes L1 control useful in several applications.



We need to set the following controller parameters for the adaptation law block,

1. τ is the adaptation gain.
2. matrix in the Lyapunov equation for P.
3. A boolean coeffcient for all estimation parameters (such as $w^{\wedge}$ and $\theta^{\wedge}$ etc.) for turning them on or off
4. Initial value for estimation parameters.
5. Projection bounds for estimation parameters either in the form of minimum and maximum value or a center of projection along with radius from the center.

Uncertainties in the plant are estimated using the adaptation law. Controller states such as ^! and ^_ etc., also known as estimation parameters, are updated in the adaptation block of the controller. We will see later in the document the meaning of these controller states. Here we just give an overview of what parameters are needed for these controller states. The adaptation law is implemented for:

$$\hat{\theta}(t)=\Gamma \mathrm{Proj}(\theta^{\wedge},-x^{-T}(t)Pbx(t)), \qquad \theta^{\wedge}(0)\ \epsilon\ \Theta$$

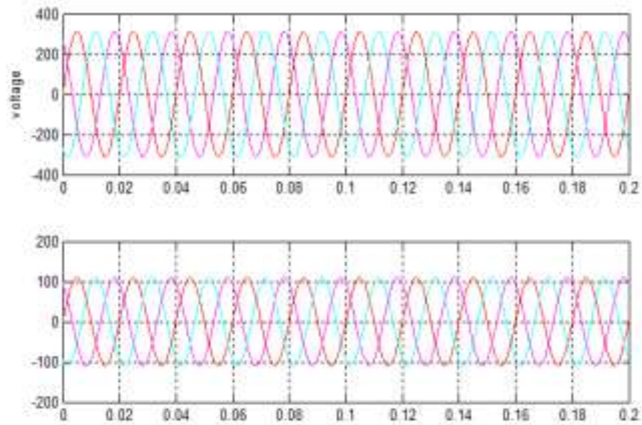
Where

$$A_m P^T + P A_m = -Q \qquad \text{where } Q=Q^T>0$$

Here Proj is an operator that is used to keep estimation parameter (in this case $\theta^{\wedge}$) within some specfied bounds.Depending on the what type of uncertainties are present in the plant, adaptation of these parameters needs to be turned on or off in the controller.

3.RESULTS AND DISCUSSION

Power generated by the system is more than the required active power for the electrical loads,the battery is absorbing the surplus power to maintain the frequency of the load voltage constant. Further the reactive power required by the load is supplied by the load-side converter to maintain the magnitude of the load voltage constant.Thus, under these conditions, both the magnitude and the frequency of the load voltage are maintained constant.Here we have some different conditions , measuring voltage and current individually at wind turbine and hydro turbine and calculating reactive and active power flow ,and comparing with the hybrid wind-hydro system which means its output active and reactive power flow of the system . In some cases the generated power is less than the active power of the load; therefore, the deficit power is delivered by the battery. During variable speed operation, the wind-turbine generator is able to maintain its coefficient of performance irrespective of the wind speed.Here we are comparing the active and reactive power flow of wind hydro turbine using adaptive filter and also with PI controller .



1.Input Voltage and current waveforms of wind turbine ,V=310v,I=120A

Fig2.Voltage and current of wind turbine

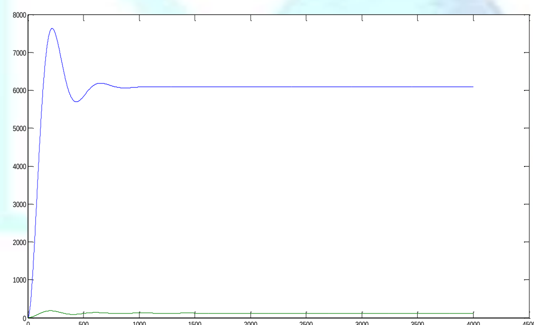


Fig3.Active and reactive power of wind turbine

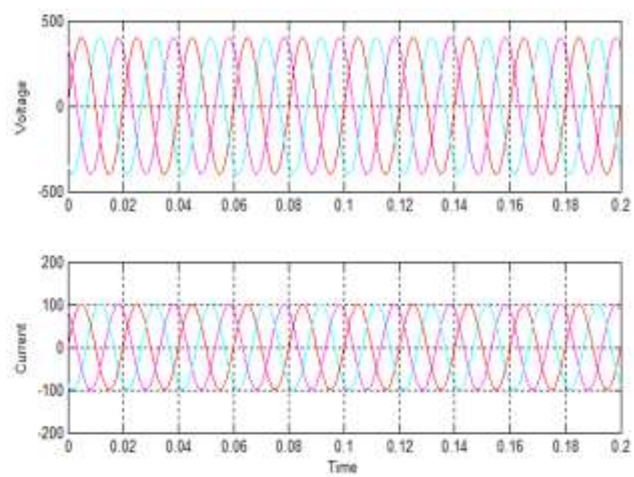


Fig4.voltage and current of hydro turbine

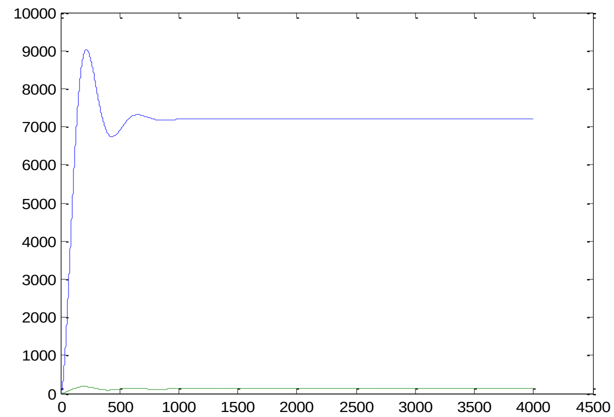


Fig5.Reactive and reactive power flow hydro turbine

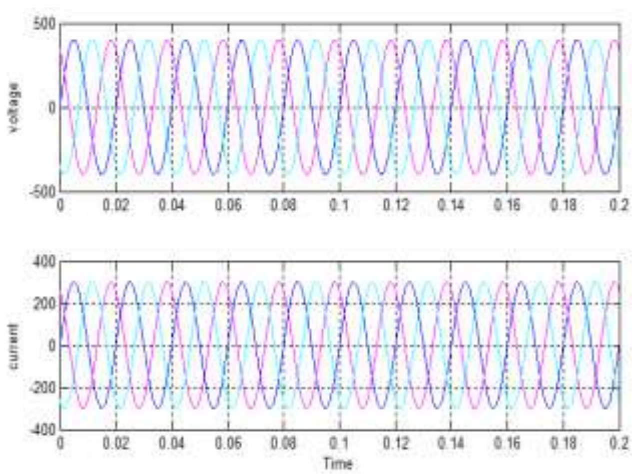


Fig6.Voltage and current of wind hydro system

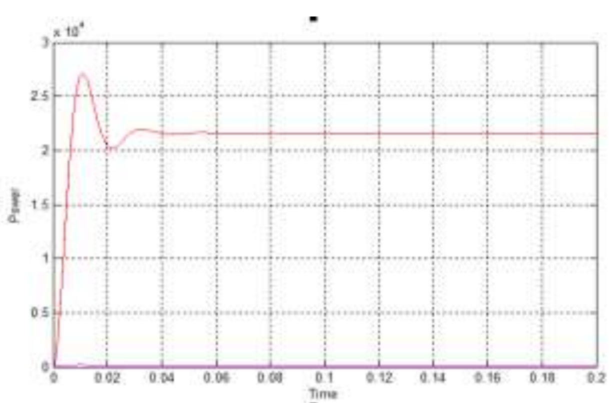


Fig7.Active and reactive power flow of wind hydro system

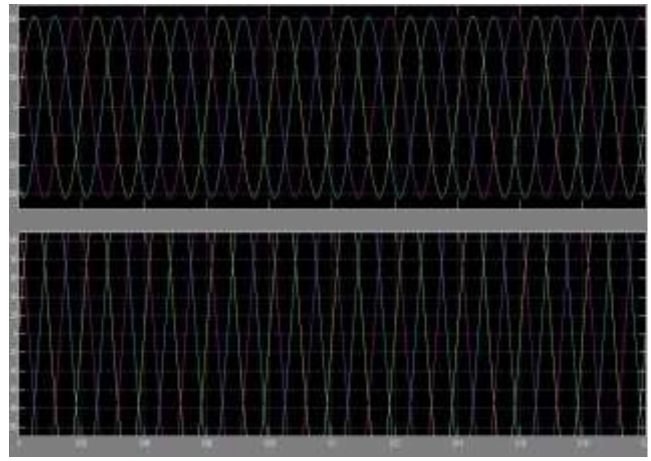


Fig8.Voltage and current of wind turbine of Adaptive Filter

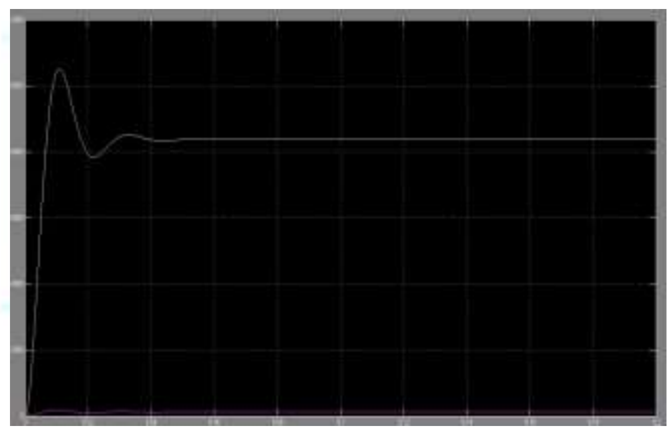


Fig9.Active and reactive power flow of wind turbine of adaptive filter

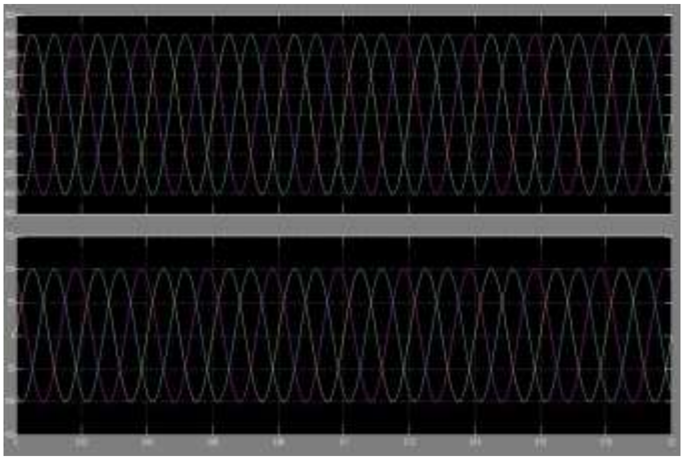


Fig10.Voltage and current of hydro turbine of adaptive filter

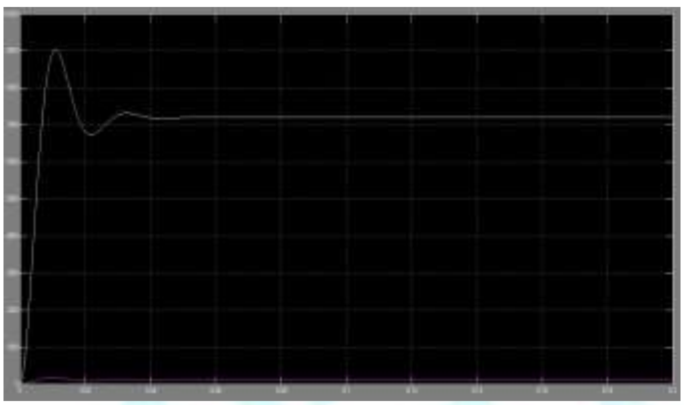


Fig11.Active and reactive power flow of hydro turbine of adaptive filter

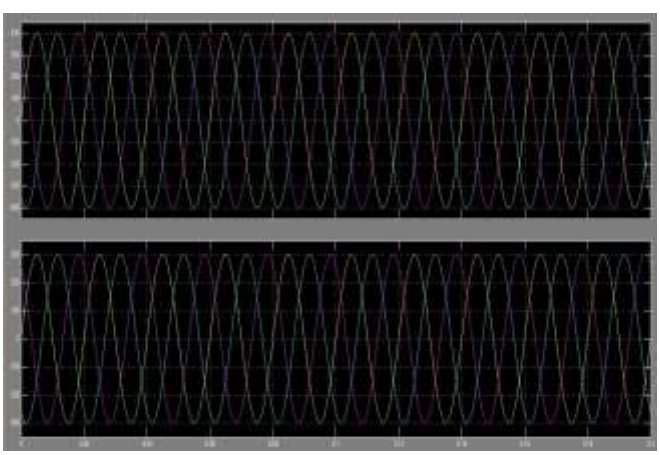


Fig12.Voltage and current of wind hydro turbine of Adaptive Filter

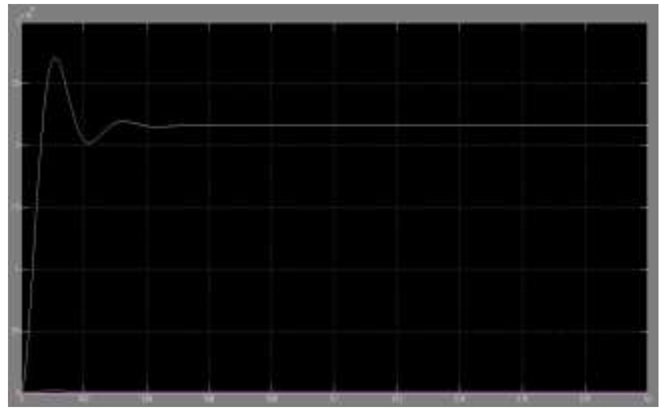


Fig13.Active and reactive power flow of wind hydro turbine of adaptive filter

4.Conclusion

Among the renewable energy sources, small hydro and wind energy have the ability to complement each other. Further, there are many isolated locations which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. For such locations, a new three-phase fourwire autonomous wind-hydro hybrid system, using one cage generator driven by wind turbine and another cage generator driven by hydro turbine along with BESS, has been modeled and simulated in MATLAB using Simulink and Sim Power System tool boxes.Here we compared the active and reactive power flow of wind hydro turbine by using PI controller and adaptive filter.Hence we came to know how voltage and current measures for these different controllers. The design procedure for selection of various components has been demonstrated for the proposed hybrid system. The performance of the proposed hybrid system has been demonstrated under different electrical (consumer load variation) and mechanical (with wind-speed variation) dynamic conditions.It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. Moreover, it has shown capability of MPT, neutral-current compensation, harmonics elimination, and load balancing.

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