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Intensifying the Power Quality in Micro Wind Energy System by the Interconnection of PID-PSO Based STATCOM Circuit

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Abstract: Micro wind energy system (MWES) is one of the well growing electric power generation systems it made to provide intended supply to a particular load. A constant range of load is fixed at all, but the generation of power is not constant in case of micro wind energy system. So power imbalance is a major problem in MWES, hence compensation circuits are used in this system to enhance the power quality. The static synchronous compensator (STATCOM) based MWES has provided better performance than the other compensation circuits. Still the power quality in MWES is not fully achieved. In this paper a modified STATCOM is developed which can enhance the power quality in MWES. The proposed STATCOM uses a hybrid artificial intelligence based controller, using proportional integral derivative and particle swarm optimization (PID-PSO). In the proposed system the PSO algorithm is used for the tuning of PID controller. The control value from the PID-PSO is given to the pulse width modulation (PWM) to generate the control signal, then based on this control signal STATCOM injects reactive power for the compensation in MWES. The performance of the proposed PID-PSO outperforms the performance of PID, PI, PD controllers.

Key words: Micro wind energy system · PID controller · STATCOM · Particle swarm optimization · Pulse width modulation

INTRODUCTION

An electric power system is a network of electrical components used to supply, transmit and use electric power. Power system consists of three separate components generation, transmission and distribution [1]. Nowadays, load shedding is the main problem in domestic as well as industrial applications. So we are implementing ancillary energy systems to meet the continuous consumption of power. In recent years, the electrical power generation from wind, is of increasing interest because of environmental problem and shortage of traditional energy source in the near future. Wind energy is considered amongst one of the cheapest and cleanest sources of electrical energy [2]. A micro wind energy system can be one of the most promising technological solutions for producing electricity in residential applications for remote consumers as well as in urban areas [3].

At present roof top solar PV systems are very popular [4], but, average cost much higher than grid connected small wind system [5] making small wind technology a viable contender for the building-integrated energy production market. Building integrated wind turbine is a generic term including any wind turbines that can be incorporated within the built environment by the way of closing to or on the buildings [6]. As the small wind turbines technology has become more mature, the market for urban applications has grown rapidly year after year [7]. Micro wind energy systems are generally located within built up areas, where wind is normally weak, turbulent and unstable in terms of direction and speed than those open sites preferable for wind farms, because of the existence of buildings and other adjacent obstructions [8, 9].

Some of the micro wind energy systems implemented in recent period. The output power of micro wind energy system is fluctuating and will affect the operation in the

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distribution network. The utility system cannot accept new generation without strict condition of voltage regulation due to real power fluctuation and reactive power generation or absorption [10, 11]. The industrial and commercial customers often operate the sensitive electronic equipment's or critical load that cannot tolerate voltage sags, Voltage swells, or loss of power, which moreover cause interruption in life operating equipment's or stoppage in industrial production. This requires some measure to mitigate the output fluctuation so as to keep the power quality in the distributed network.

Power quality in the micro wind energy system can maintain by the interconnection of compensation circuits, so far many research works have been done to increase the power quality in micro wind energy systems. The combination of battery energy storage and micro-wind generating system in distributed power system is used, which provides effective, reliable and durable power system [12-14]. The system also provides energy saving and un-interruptible power within distribution network. The power electronics based conversion of energy was implemented on small wind turbine systems for the better performance [15].

Related Work: Some of the recent related work related to the micro energy system of intended used and security enhancement is listed as follows:

Engin Cetin *et al*. [16] have investigated a residential application of photovoltaic–wind/fuel cell hybrid energy system established at the Clean Energy House. The study was based on the distribution and consumption of Direct Current (DC) electrical energy which was produced by the hybrid system. For this purpose, a DC distribution panel has been constructed and some 12 V and 24V loads, obtained from the market, have been energized through this panel. In the residence, 12V and 24V voltages have been used for safer conditions i.e. not only for inhabitants but also the devices in the residence. The need for AC conversion is overcome by distributing and consuming the DC energy in a DC manner. The DC distribution eliminates the cost of conversion, the electrical losses during conversion and also the need for some space required by the inverter. In result, they constructed a residence concept where the 12V and 24V loads are located and energized by some renewable energy sources.

A.S. Bahaj *et al*. [17] have addressed modeling of installations and presented methodology to assess the suitability and the economic viability of micro wind turbines for domestic dwellings. A modeling tool "µ-Wind" was developed specifically for studying both energy yields and the payback periods for micro wind turbines. µ-Wind predicts wind turbine performance prior to installation according to specific power curves either defined by turbine manufacturers or the user. Numerical consideration of wind speed data at specific sites was used to estimate energy yields and the results was projected to real electricity demand data from monitored dwellings. The results showed that it was possible to predict with a good degree of accuracy the expected financial payback period for a typical domestic dwelling. Furthermore, the paper postulated that micro-wind technology could have the potential to make a significant impact upon domestic electricity generation when located at the windiest sites.

In the micro-grid network, it is especially difficult to support the critical load without uninterrupted power supply. S.W. Mohod and M.V. Aware [18] have proposed a micro-wind energy conversion system with battery energy storage was used to exchange the controllable real and reactive power in the grid and to maintain the power quality norms as per International Electro-Technical Commission IEC-61400-21 at the point of common coupling. The generated micro-wind power was extracted under varying wind speed and was stored in the batteries at low power demand hours. In this scheme, inverter control was executed with hysteresis current control mode to achieve the faster dynamic switchover for the support of critical load. The combination of battery storage with micro-wind energy generation system (µ WEGS), which will synthesize the output waveform by injecting or absorbing reactive power and enable the real power flow required by the load. The system reduced the burden on the conventional source and utilizes µ WEGS and battery storage power under critical load constraints and provided rapid response to support the critical loads.

Peng Wang *et al*. [19] have proposed a technique to evaluate operational reliability and energy utilization efficiency of power systems with high wind power penetration. The ramp rate of a conventional generator and energy storage system (ESS) were considered in the proposed technique. The effect of slow ramp-up rate or fast reduction of wind speed on system reliability was measured by the expected energy not supplied. An index designated as the expected energy not used was proposed and formulated to represent energy surplus due to fast increase of wind speed and slow ramp down of conventional units.

Lei Zhang and Yaoyu Li [20] have concerned with the optimal energy management for a wind-battery hybrid power system (WBHPS) with local load and grid connection, by including the current and future information on generation, demand and real-time utility price. When applying typical dynamic optimization schemes to such a problem with a single time scale, the following dilemma usually presents: it was more beneficial to plan the (battery) storage set point trajectory for the longer horizon, while prediction of renewable generation, utility price and load demand is more accurate for the shorter term. To relieve that a two-scale dynamic programming (DP) scheme was applied based on multi scale predictions of wind power generation, utility price and load. A macro-scale dynamic programming (MASDP) was performed for the whole operational period, based on long-term ahead prediction of electricity price and wind energy. The resultant battery state-of-charge (SOC) was thus obtained as the macro-scale reference trajectory. As the operation proceeds, the micro-scale dynamic programming (MISDP) was applied to the short-term interval based on short-term three-hour ahead predictions. The MASDP battery SOC trajectory was used as the terminal condition for the MISDP. Simulation results showed that the proposed method could significantly decrease the energy cost compared with the single scale DP method.

Proposed Micro Wind Energy System for Power Quality Improvement Using Statcom: Micro wind energy (MWE) system is one of the motivated power generation techniques, to fulfill the electric power need in an intended service. However the direct interconnection of MWE system to the load can lead power imbalance and reduces the power quality. So some compensation circuits are needed to compensate the power stability problem. In this paper a static synchronous compensator (STATCOM) is used in the MWE system to compensate the power imbalance. STATCOM is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. The STATCOM can inject or absorbs reactive power by the inductive or capacitive reaction at voltage sag or swell condition respectively. The outcome of STATCOM is completely depends on a controller circuit, which compares the source voltage with reference voltage and produce a control signal. Based on the control signal the STATCOM produce output, i.e., either inject or observe reactive power. Hence this controller circuit took one of the major processes, so research on this control circuit in the STATCOM is a current trend. In this sense this paper developed a new control scheme for the STATCOM using PID-PSO controller. The proposed PID-PSO controller based STATCOM for MWE system is shown in Fig. 1.

Modeling of STATCOM: Because of the high dynamic performance, STATCOM has become one of the most effective equipment for reactive power compensation. The compensation does not depend on the common coupling voltage, which makes STATCOM solution attractive due to its advantages: precise and continuous reactive power control with fast response and minimal interaction with power grid. STATCOM is becoming a predominant new generation devices for flexible AC transmission systems (FACTS). Figure 2 shows a typical STATCOM configuration from [*1].

STATCOM is a Multiple Input Multiple Output (MIMO) system. Thus a multivariable control approach is needed for the STATCOM control design. Although it is not possible to totally decouple the system variables, there is one powerful tool for studying balanced three phase system, which converts the three phase voltages and currents into orthogonal components in a synchronous rotating frame by Park Transform. The MIMO system will be simplified for the decoupling method. The orthogonal components in the rotating frame are referred to as active and reactive components. The proposed approach for PID controller design and synthesis will be applied for the decoupled control variable. The mathematical expression of the STATCOM system is given in equation (1) to (4). [*1]

$$\frac{di_d}{dt} = -\frac{R}{L} i_d + \omega i_q + \frac{1}{L}\left(V_{td} - V_{sd}\right) \tag{1}$$

$$\frac{di_q}{dt} = -\omega i_d - \frac{R}{L} i_q + \frac{1}{L}\left(V_{tq} - V_{sq}\right) \tag{2}$$

$$\frac{dV_{dc}}{dt} = -\frac{3\left(V_{td} i_d + V_{tq} i_q\right)}{2CV_{dc}} - \frac{i_L}{C} \tag{3}$$

$$Q = \frac{3}{2}\left(V_{sq} i_{sq} - V_{sd} i_{sd}\right) \tag{4}$$

where ω is the angular power frequency and subscripts d, q represent variables in the rotating coordinate system for the components of direct and quadrature axis, respectively.

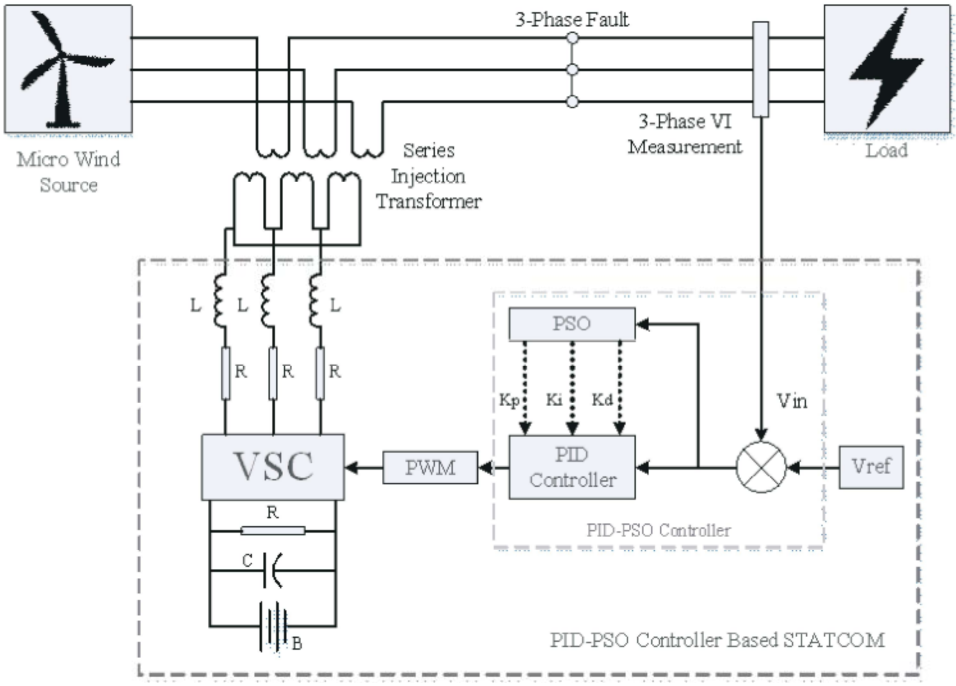


Fig. 1: Proposed Micro wind energy system

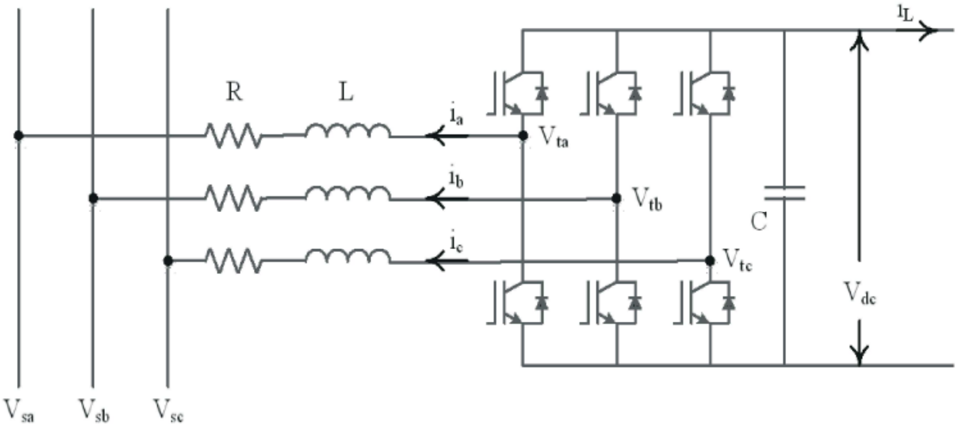


Fig. 2: STATCOM system configuration

Choosing the states x, the inputs u and the output y by:

$$x = \begin{bmatrix} i_d \\ i_q \end{bmatrix}, u = \begin{bmatrix} V_{td} - V_{sd} \\ V_{tq} - V_{sq} \end{bmatrix}, y = \begin{bmatrix} i_d \\ i_q \end{bmatrix}, \tag{5}$$

The equations (1) and (2) can be rewritten to the state space transfer function as the linear system:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \tag{6}$$

where the corresponding coefficient matrices are:

$$A = \begin{pmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{pmatrix}, B = \begin{pmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{pmatrix}, C = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

The detailed STATCOM control block diagram is described in [*2], which includes two control loops in the whole system for the decoupled variable.

Modeling of PID Controller for STATCOM: PID controller is one of the most common controlling devices in the market. Because of its very simple control structure and the linear control methodology, PID control is generically important in many industries and has been widely used in electrical, mechanical, hydraulic, fluidic and pneumatic systems [21]. It can provide the set point regulation of zeroing error under arbitrary low frequency disturbances and it owns robust characteristics for those modeling errors. Three term controllers are easier to adjust at the design stage as well as online.

Consider the general feedback system with a PID controller and plant transfer function $G(s)$, which is shown in Figure 3.

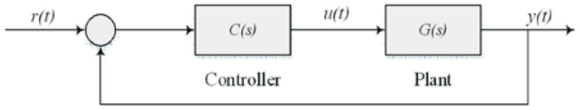


Fig. 3: A feedback system with PID controller

where $r(t)$ is the reference signal, $u(t)$ is input signal, $y(t)$ is the output, $C(s)$ is the controller to be designed. For the PID controller, $C(s)$ will be:

$$C(s) = k_p + \frac{k_i}{s} + k_d s \tag{7}$$

where k_p, k_i and k_d are the proportional, integral and derivative gains respectively. In some cases when the error is measured in a noisy environment, a delay part for the transfer function should be considered as:

$$C(s) = \frac{sk_p + k_i + k_d s^2}{s(1+sT)},\ T > 0 \tag{8}$$

where T is usually a small positive value and the design of PID controller is to determine the values of coefficients k_p, k_i and k_d, which could make the controller stabilize the given plant.

Modeling of PID-PSO Controller: Industrial control field usually has the control systems like non-linearity, including robot system, spacecraft system, vehicle system, power system, etc. On the other hand the PID control technique has widely used because of its applications like simple mechanism and clear physical conception. In recent era the researchers concentrated on intelligent controlling techniques for example, fuzzy control, neural network control and decoupling control etc., however in intelligent controller getting precise control performance is a complex task. Because it is difficult to control a complex non-linear system without the interaction of human intelligence, hence adaptive controlling techniques has the ability to adjust control parameters effectively. It can tune complex systems better by combining nonlinear controlling methods and intelligent control technology. Hence in this paper a hybrid PID-PSO controller technique is used for the controlling of STATCOM connected micro wind energy system. The Fig. 4 shows the PID-PSO controller circuit.

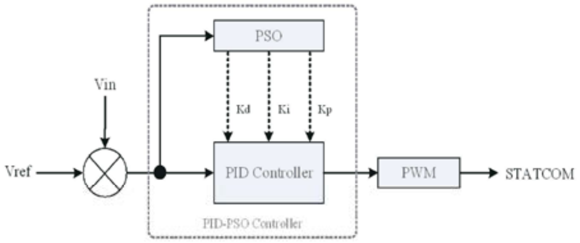


Fig. 4: PID-PSO controller

In the above Fig. 4, V_{ref} is the reference output and V_{in} is the system output at the sampling point. Optimization algorithm such as adaptive particle swarm optimization algorithm is used in our case to adjust the PID controller parameters such as K_p, K_i and k_d. In the same way, mean squared errors will be defined as the objective function is given in eqn. (9).

$$MSE = \frac{1}{N}\sum_{k=1}^{N}(Er)^2 = \frac{1}{N}\left[V_{ref} - V_{in}\right]^2 \tag{9}$$

Our work optimizes the developed prediction model not only based on the weights to be optimized but also based on the hidden sub-models of the prediction model using PSO. The PSO operation is given below:

Step 1: Initialize A_H by a random integer between the interval $(-I, I)$ along with appropriate velocities.

Step 2: Generate initial particles of length $(A_I \times A_H) + A_H$ in which the first particles are randomly generated between the intervals $(-I, I)$

Step 3: Generate arbitrary velocities as similar in length to that of the initial particles.

Step 4: Evaluate every particle using the error function as follows.

$$Er(K) = Z_r(K) - Z(K) \tag{10}$$

where, $z_r(K)$ is the reference output and $z(K)$ is the system output.

Step 5: The particles that are succeeding in the evaluation function with minimum value are selected and the corresponding particles are updated using the velocity update formula. The velocity update formula for PSO can be given as:

$$v^{new} = v^{old} + b_1 \times I(0,1) \times (p_{best} - p) + b_2 \times I(0,1) \times (g_{best} - p) \tag{11}$$

$$p^{new} = p + v^{new} \tag{12}$$

where, v^{old} and v^{new} is the old and new updated velocities respectively, b_1 and b_2 are constants, $I(0,1)$ is a uniformly distributed random integer, p_{best}, p, g_{best} and p^{new} are the best of the particles, particle to be updated, best particle as selected globally and newly updated particle, respectively.

Since the random values of b_1, b_2 in the velocity computation does not select the optimal parameters so that the result also in random. Therefore, we have proposed an Adaptive particle swarm optimization (APSO) method with the selection of coefficients values by using the particles fitness values. The APSO method selects the optimal parameters and provides more accurate result. The adaptive PSO (APSO) coefficients are determined by,

$$db_1 = \frac{2}{3}\left(b_{1\max} - b_{1\min}\right)\left(\frac{T_{\min}}{T_{avg}} + \frac{T_{\min}}{2T_{\max}}\right) + b_{1\min} \tag{13}$$

$$db_2 = \frac{2}{3}\left(b_{2\max} - b_{2\min}\right)\left(\frac{T_{\min}}{T_{avg}} + \frac{T_{\min}}{2T_{\max}}\right) + b_{2\min} \tag{14}$$

where $b_{1\max} = 3$ and $b_{1\min} = 1$ represent the maximum and minimum values of b_1 and $T_{\min}$, T_{avg} and $T_{\max}$ are the particles minimum, average and maximum fitness values. Whereas $b_{2\max} = 3$ and $b_{2\min} = 1$ represent the maximum values and minimum of b_2 respectively. By applying these db_1 and db_2 coefficients values in the velocity equation (3), the equation is updated.

RESULTS AND DISCUSSION

The proposed system for the power quality control in micro wind energy system using STATCOM based on PID-PSO controller is implemented in the working platform of Matlab/Simulink. The proposed micro wind energy system is designed with the initial parameter setting given in Table 1.

Table 1: Initial parameter setting

Parameter	Value
Maximum Micro wind capacity	10kW
Total Load	7kW

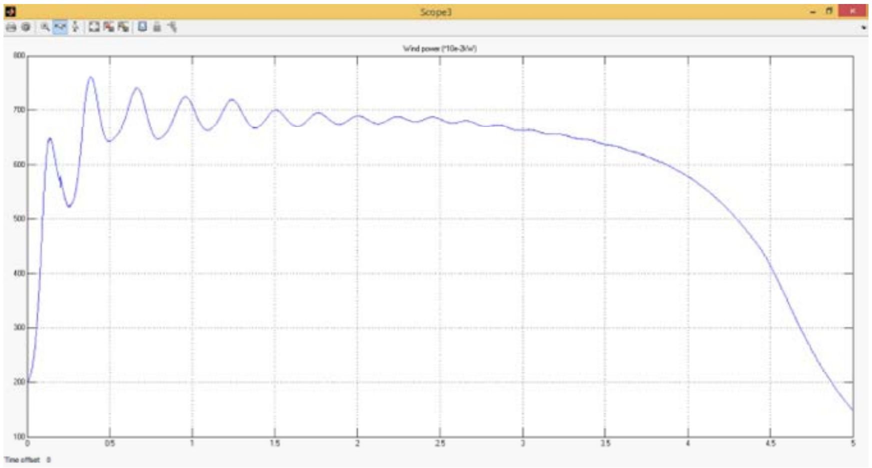
The performance of the proposed system for the stabilization of micro wind energy system is analyzed based on two cases they are voltage sag and Voltage swell. Voltage sag and swell are the major two conditions on which the power system is stability is not achieved. Voltage sag is a short duration reduction in rms voltage which can be caused by a short circuit or short circuit and Voltage swell is the opposite of voltage sag. Voltage swell, which is a momentary increase in voltage, happens when a heavy load turns off in a power system. The improvement of performance of the proposed system is proved by comparing with the conventional PID controller. The results at various conditions are shown in Fig. 5-11.

In Fig. 5 the generating power as well as the required load power is given, the total capacity of micro wind turbine used in the proposed paper is 10kW and the total required load is set at 7kW. The total power generated at the current instance is average of 7kW hence there is no need of compensation and it is consider as the normal condition. Then the results at the most possible power quality problems like voltage sag and Voltage swell is given below.

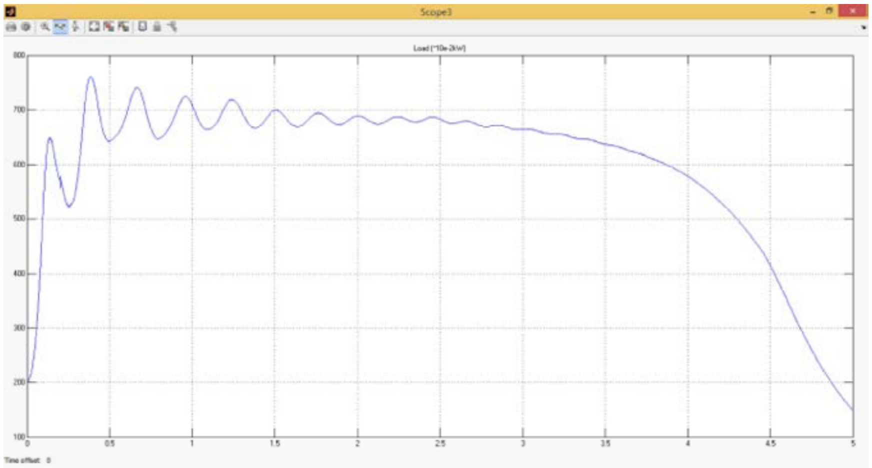
At voltage sag condition the generating power is lower than the required power the waveform obtained at the voltage sag condition is given in fig 6. In this case the generating power is average of 4.5kW but required power is 700kW hence compensation is required to fulfill the required load demand. In the proposed paper the STATCOM with PID-PSO controller scheme is used for the compensation and the results obtained in compensation is compared with the conventional controller based STATCOM like PI, PD and PID controllers.

Figure 7 shows the various STATCOM output at voltage sag condition is given, where the various compensator output is given and its corresponding load power (after compensation) is given in Fig. 8.

After the compensation the proposed system have fulfill the compensation that is it produce almost 7kW power after compensation but the other system produces below 7kW hence the proposed PID-PSO based STATCOM is suitable for micro wind energy system at voltage sag condition.



(a) Micro wind generating power



(b) Required Load power

Fig. 5: Generation and load power at Normal condition

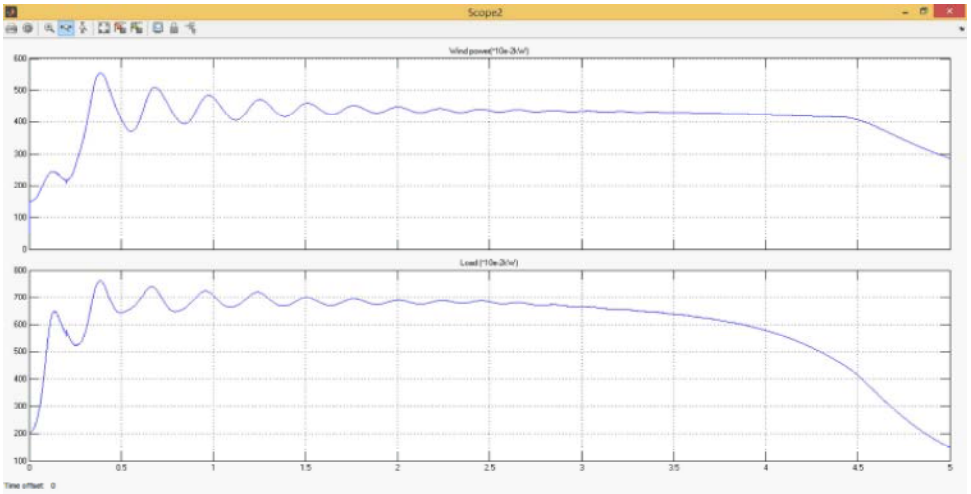
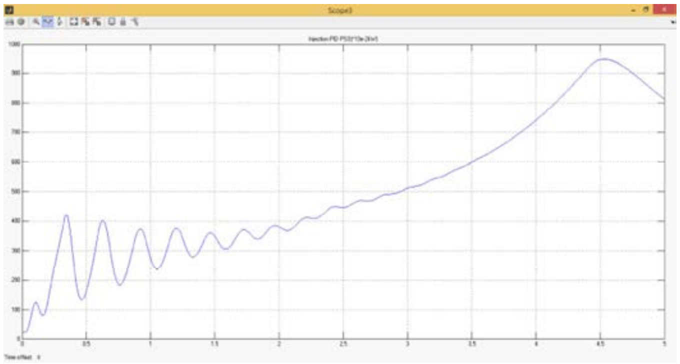
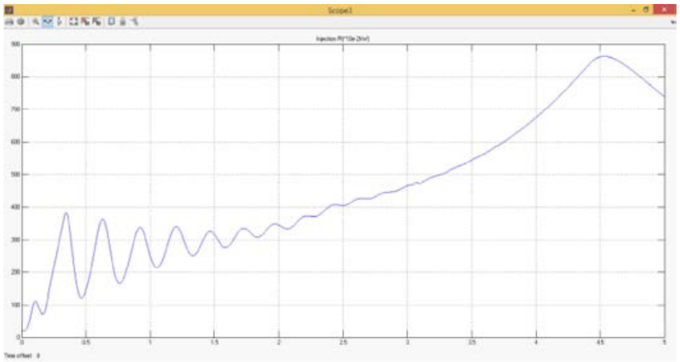


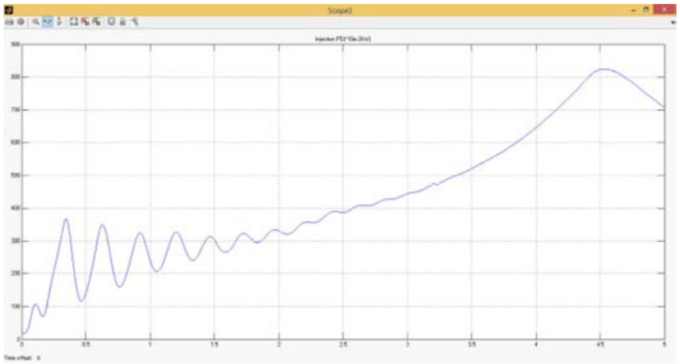
Fig. 6: Generation and load power at voltage sag condition



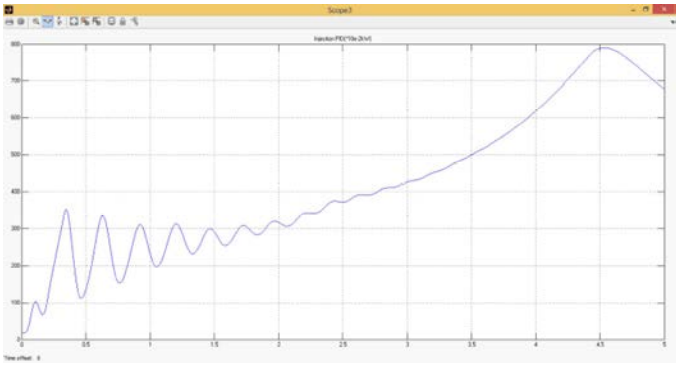
(a) PID-PSO



(b) PI

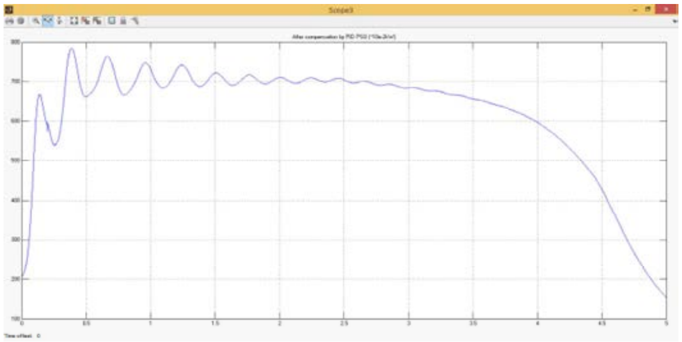


(c) PD

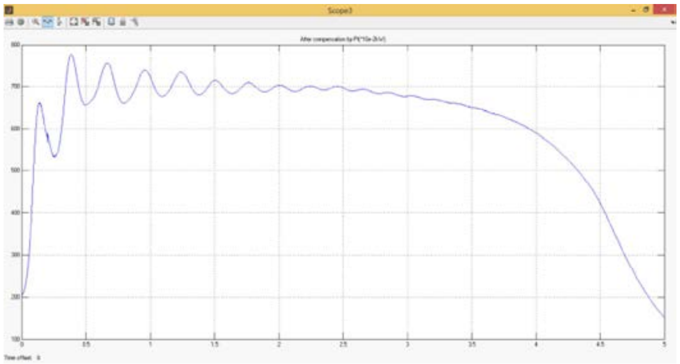


(d) PID

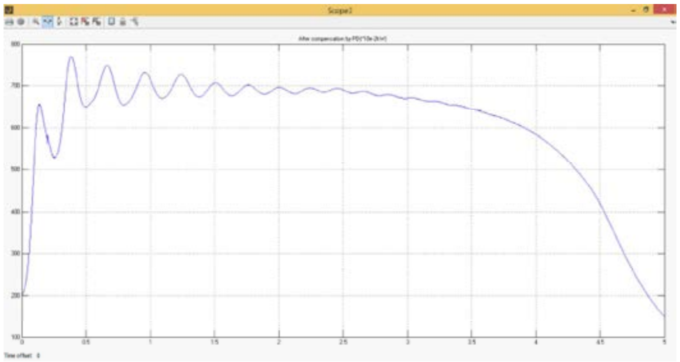
Fig. 7: STATCOM output at voltage sag condition



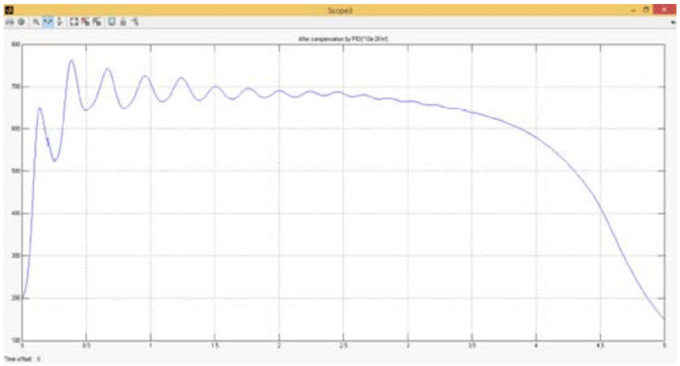
(a) By PID-PSO



(b) By PI



(c) By PD



(d) By PID

Fig. 8: Load after compensation at voltage sag condition

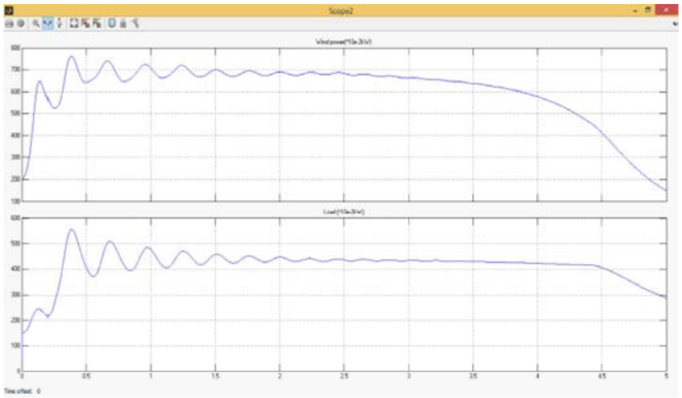
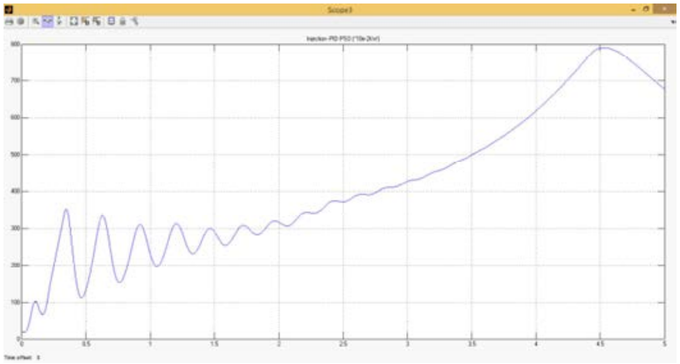
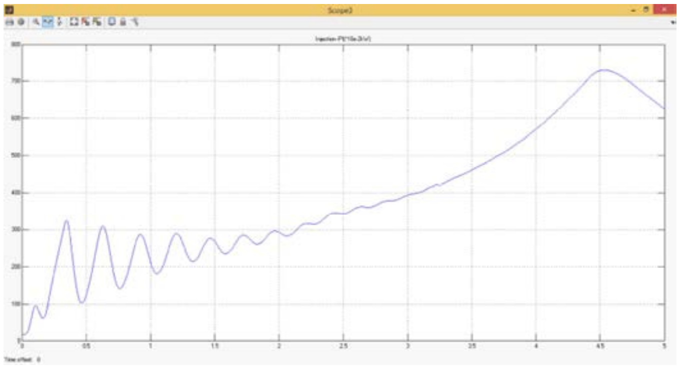


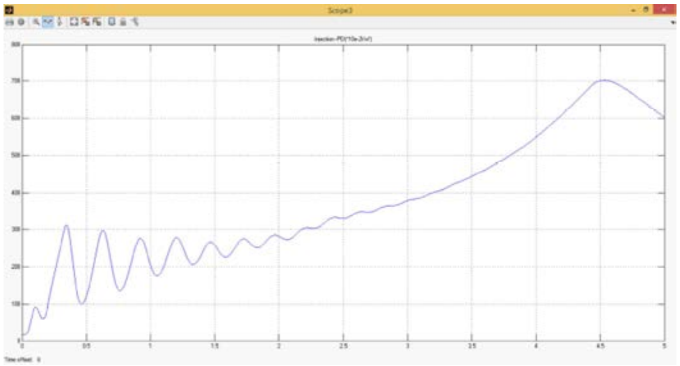
Fig. 9: Generation and load power at Voltage swell condition



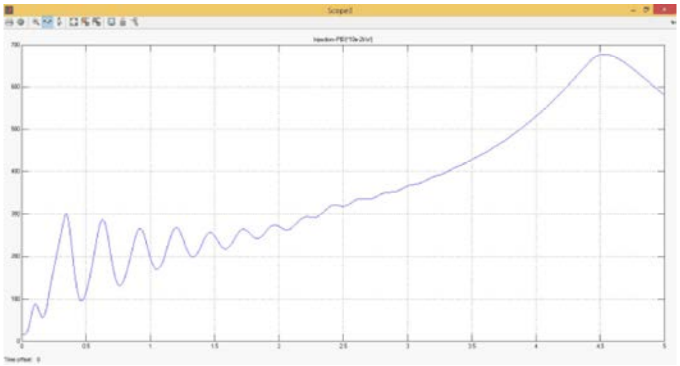
(a) PID-PSO



(b) PI

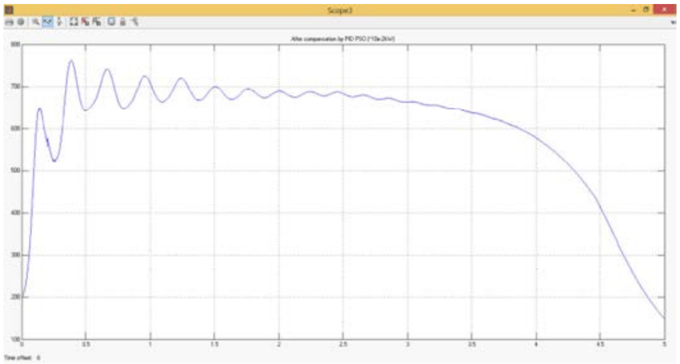


(c) PD

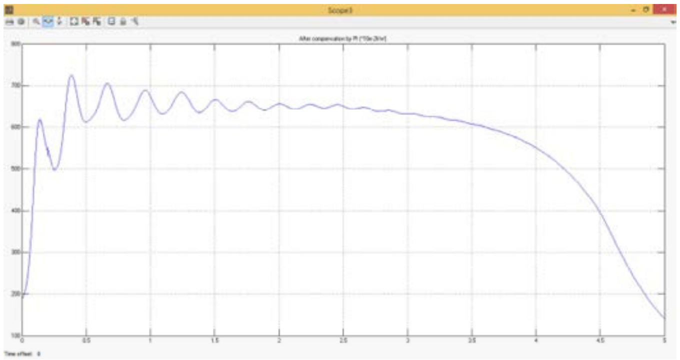


(d) PID

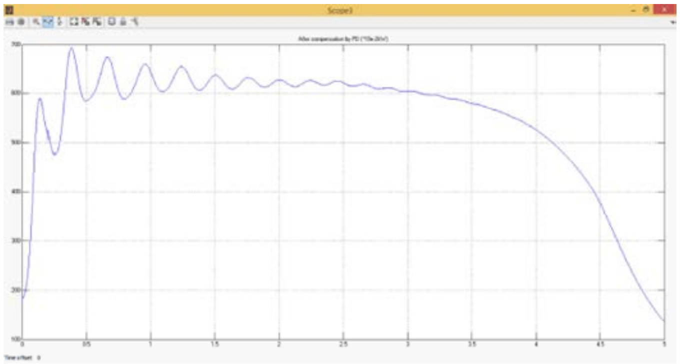
Fig. 10: STATCOM output at Voltage swell condition



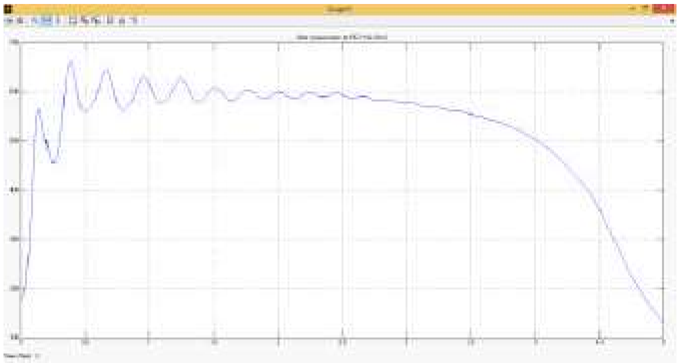
(a) By PID-PSO



(b) By PI



(c) By PD



(d) By PID

Fig. 11: Load after compensation at Voltage swell condition

Voltage swell is another kind of power quality problem at this condition the generating power is higher than the required power which is shown in Fig. 9 and the compensation output various techniques like PI, PD and PID is given in Fig. 10 and 11.

Fig. 10 shows the absorption of reactive power for the compensation purpose to the power system to compensate the swell voltage by various controller based STATCOM.

The power obtained after the compensation is given in Fig. 11 similar to the sag condition the compensation strength of proposed system is better than the other techniques at swell condition too. From these performance analyses the performance of the proposed system shows that at different condition it can operate well and provide effective compensation than the other conventional controller based STATCOM in micro wind energy system.

CONCLUSION

A system proposed in this paper for the compensation of power imbalance in micro wind energy system using PID-PSO based STATCOM circuit. In the proposed system the hybrid PID-PSO controller is used for the STATCOM to compensate the power quality problems like voltage sag and Voltage swell. The proposed system is implemented in the Matlab/Simulink platform and the results are compared with conventional controller based STATCOM like PI, PD and PID. The performance results suggest that the proposed PID-PSO controller based STATCOM has the better performance than the convention et al controller based STATCOM for the compensation in micro wind energy system. Hence this proposed system is become better option in real time wind energy system for the improvement of power qualities. In future the system performance can further enhanced by utilizing different compensator or by novel controlling strategy.

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