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Particle Swarm Optimization Based Voltage Control using STATCOM for Solar - WindHybrid Micro-Grid

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Abstract—

Power generation from the breeze and sun based photovoltaic (PV) frameworks are profoundly needy upon climate conditions. Their irregular nature prompts changes in their yield. Thusly, the requirement for fast remuneration for vitality transmission and appropriation frameworks is progressively significant. Static Synchronous Compensator (STATCOM) can be embraced for receptive force remuneration and for diminishing the voltage variance brought about by the framework and sustainable power sources. This investigation presents displaying of a Solar PV-Wind Hybrid Micro-lattice and the expansion of the stable working restriction of the framework if there should arise an occurrence of the joining of STATCOM is inspected. The significant commitment of this paper is the streamlining of addition boundaries of four PI regulators in STATCOM dependent on hereditary calculations (GA) and Particle swarm advancement (PSO) procedure, along these lines getting better reactions and voltage solidness as far as nonlinear nature of sun powered breeze mixture miniature matrix. The Simulink models of the framework design incorporate a 2 MW wind turbine model dependent on doubly took care of acceptance generator (DFIG), 0.4 MW sun based PV power framework model and a STATCOM appraised at 3 MVAR. It is guaranteed that the voltage change toward the finish of the bus bar is diminished by 8 % utilizing ordinary PI regulator. The outcomes acquired by PSO-based streamlining of PI regulators are contrasted and GA based regulator and better outcomes accomplished..

Key words—Flexible AC transmission systems; Genetic Algorithm; PV-Wind hybrid system; Static synchronous compensator; Voltage control

I. INTRODUCTION

The utilizations of sustainable power sources have indicated expanding energy, particularly as of late. Expanding vitality utilization, quick advancement in vitality creation advances and expanding public mindfulness for ecological security lead research zones to elective vitality and conveyed creation. By utilizing different control methods, it is conceivable to make a crossover structure comprising of a proficient photovoltaic (PV) framework and wind vitality framework for applications with low introduced limit. Since sustainable power source frameworks, for example, twist alone and half breed Wind/PV are not totally safe in satisfying the need for the heap, power dangers are experienced and responsive force remuneration is a rising requirement for stable activity of a mixture framework. Responsive force remuneration is a necessity in all vitality frameworks. Responsive force causes concerns engaged with various force quality issues just as expanding power misfortunes. To illuminate this, the coordinated condensers and fixed mechanical exchanging capacitors have been utilized for a long time. Pay of this sort have a few inconveniences, for example, huge measurements, high misfortunes and moderate reaction time.For reducing power quality issues, improving framework strength and for expanded force move capacity, the FACTS (Flexible Alternating Current Transmission Systems) gadgets have been financially presented in the last part of the 1980s [1]. Be that as it may, new FACTS geographies are developing to upgrade the security and adjustment of miniature networks [2], [3]. As an individual from FACTS family gadgets, STATCOM is a shunt-associated inverter-based gadget that improves power quality in substituting current frameworks. The principal establishment of the STATCOM was in Japan in 1991. It gave voltage adjustment appraised at ±80 MVAR [1]. From that point forward, with the presentation of continuous regulators, progressed and complex control calculations could be actualized [4]. The part of

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these gadgets is power factor

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improvement, load adjusting, voltage guideline and symphonious end in vitality frameworks. By expanding the limit of transmission lines, the need to construct new lines are killed. Different control techniques are utilized to permit power framework activity inside the necessary working cutoff points. The most normally utilized regulators are Proportional-Integral (PI), Proportional-Integral-Derivative (PID), Fuzzy Logic Controller (FLC) and Artificial Neural Networks (ANN)- based regulators. In business STATCOM gadgets, by and large, customary PI type regulators are fused and the viability of the regulator decides the exhibition of STATCOM. Accordingly, the ebb and flow research is centered around getting a more hearty and versatile activity of STATCOM for varieties of the half and half force framework.

Lately, different investigates on STATCOM have been made. In 2010, it is completed exploration on a half and half PV-Wind flexibly framework with STATCOM interface for a water-lift station and diminished voltage variance in a restricted way [5]. In the writing, a few investigations have talked about the effect of FACTS regulators on the solidness of intensity frameworks associated with doubly took care of enlistment generators and zeroed in on the consequences of rotor point reactions [6]. A control strategy for VSC (voltage source control)- based STATCOM utilizing customary and direct-current vector control systems has been proposed. Yet, it just chipped away at the voltage change from the framework and they didn't manage a crossover framework [7]. Voltage control through responsive force uphold for wind vitality change framework based mixture power framework has been accounted for in [8]. Yet, the work didn't utilize STATCOM to decrease the voltage change with the heap side converter. An equal reverberation connect type shortcoming current limiter (PRBFCL) to enlarge the transient security of a half breed power framework has been accounted for in [9], and voltage variance has been diminished with this technique. The writing survey shows that there is almost no exploration on the STATCOM framework based voltage vacillations brought about by the cross breed sunlight based breeze microgrid. With the expanding establishment of PV and wind power frameworks, the customary FACTS gadgets actually need upgrades by enhancements of regulators and broad examination must be made under different working conditions. Reference [10] introduced the dynamic reaction of crossover power frameworks with the ideal increase setting of STATCOM. Reference [11] proposed a strong control utilizing SVC and Automatic Voltage Regulator (AVR). The hereditary calculation is utilized to tackle an enhancement issue and all the while get PI control boundaries of SVC and AVR. Reference [12] played out a searcher advancement calculation for the disengaged half breed power framework model-execution investigation of a Takagi-Sugeno fluffy rationale (SOA-TSFL) based regulator.

In this investigation, the goal is to expand the solid working restriction of the introduced power framework design by fusing STATCOM for responsive force remuneration. Additionally, it is planned to decrease the voltage vacillation happening because of the differing idea of sustainable power sources. Ideal alteration of PI boundaries in STATCOM is naturally made dependent on GA to get an agreeable reaction. The improvement of the PI regulator boundaries in STATCOM control circuit is performed. To the best information on the creators, an examination managing the streamlining and change techniques for four PI regulators in the STATCOM's control circuit for voltage soundness of the PV-Wind cross breed framework has not been distributed. .

I. WIND POWER SYSTEM MODELLING

Today, Doubly Fed Induction Generator (DFIG) is one of the most favored breeze generators [13]. DFIG is made out of stator windings that are associated legitimately to a fixed recurrence 3-stage organization and consecutive voltage-based converters put in rotor windings. The term doubly-took care of implies that the stator voltage is gotten from the mains and the rotor voltage is instigated by the force converter. The framework takes into account huge yet restricted variable velocities (can work with a speed contrast of ± 40 %). The transducers make the mechanical and electrical

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recurrence alteration by infusing flow at various frequencies to the rotor. Generator conduct is overseen by power converters or regulators in ordinary activity or deficiency conditions [14].

The DFIG comprises of progressive voltage-prompted converters, which are associated legitimately to the fixed recurrence three-stage network and are bi-directionally associated with the rotor windings. The force converter unit incorporates two converters; the rectifier on the rotor side and the inverter on the lattice side control one another. The primary thought is to control the rotor current segments of the rectifier on the rotor side and control the dynamic and responsive forces. The inverter on the matrix side likewise controls the DC connect voltage and guarantees that the activity of the converter is coordinated with the force factor.

DFIG has numerous preferences, for example, the controlling ability of dynamic and receptive force by rotor current [14]. It has two progressive converters as rotor side control and framework side control in Fig. 1. In the framework side control circuit of the breeze, Vbus (network voltage), Q (responsive force part), three-stage current segment (Ia, Ib, Ic) are taken in the matrix side control circuit of the breeze and Vbus and Id&Iq are managed. With space vector changes, voltage segments (Vd&Vq) and current segments (Iq&Id) are changed over to three-stage signals. The points are resolved with PLL by utilizing voltage esteems and utilized in space vector change (Park and Clarke)..

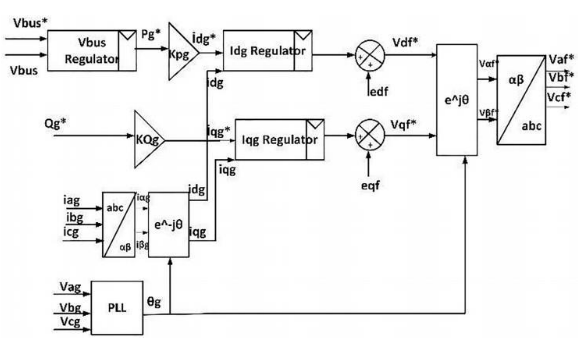

Fig. 1. Grid side control circuit.

The control circuit is actualized in Simulink condition. The streamlined model presents the intensity of the rotor by figuring the mechanical force as a component of wind current on the edges [15]. Wind speed (Vw) is considered as the normal speed on the region cleared by the cutting edges.

The force condition delivered by the breeze turbine is yielded (1)

(1)

The amount of aerodynamic torque is given in (2)

(2)

Wind turbine end velocity ratio is given in (3)

(3)

Power coefficient (Cp) alludes to the expository articulation as a component of the edge of tendency (β) and the turbine end speed proportion (∂), k is a consistent, R is proportion, C_t is the coefficient of force, An is surface, r is the air thickness, Ω_t is the rakish speed of the rotor.

The power factor equation is given in (4) and (5) [15]:

(4)

(5)

In view of these conditions, the qualities in Fig. 2 are gotten. As can be seen from the figure, if the breeze speed is 12 m/s, the yield power arrives at 2 MW. As indicated by these force and force conditions, a breeze turbine model is shaped and aberrant speed control is demonstrated to decide the greatest force point. Some information for the Doubly Fed Induction Machine were embraced and a DFIG was demonstrated [15].

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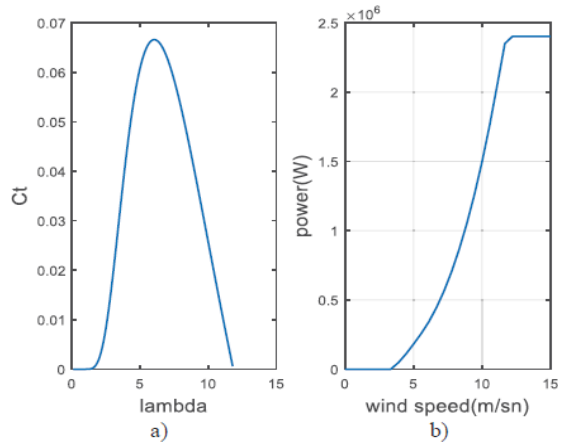

Fig. 2. Characteristics of wind turbine: a) λ-Ct characteristic; b) Velocity- Power (v-P) characteristics.

II. PHOTOVOLTAIC POWER SYSTEM MODELLING

Sun powered PV boards guarantee the prodction of power in DC structure by changing over the vitality in the sun's beams. So as to build the power yield, numerous sun oriented cells are associated in equal or in arrangement and mounted on a surface framing a sun based cell module or a photovoltaic module. The PV cells are demonstrated utilizing the one-diode comparable circuit. The PV current can be resolved as appeared in (6) [16]

(6)

where k is Boltzmann gas constant (1.38 ×J/K), T is absolute temperature (K), q is electron charge (1.6xC), n is linearity factor, Rs is the series resistance, Rsh is the cell shunt resistance, Ns is number of PV module in series, V is the output voltage of solar cell and I0 shows the dark saturation current value.

The numerical model of the photovoltaic framework with the conditions itemized in [16] is actualized in Simulink. Likewise, bother and watch (P&O) calculation is utilized for the maximum power point tracking (MPPT) in the framework..

III. STATIC SYNCHRONOUS COMPENSATOR.

STATCOM depends on a voltage source DC/AC converter. At the STATCOM yield, adjusted three-stage voltages are gotten at the mains recurrence, with controllable sufficiency and stage point. In this exemplification, the consistent state power trade between the AC framework and the gadget is commonly receptive. The receptive force trade between the STATCOM and the AC framework is constrained by controlling the size and stage edge of the transformer yield voltage. For this, the size and recurrence of the air conditioner yield voltage of the inverter in the STATCOM circuit must be set. In the event that the size of the yield voltage of the STATCOM surpasses that of the AC framework voltage (Vstatcom > Vac), the current streams from the STATCOM to the AC framework through transformer reactance and the gadget creates receptive force for the transmission line.

In the event that the STATCOM yield voltage is bigger than the transmission line voltage, the gadget works in capacitive mode. The capacitor is utilized to give the DC voltage needed to the inverter. The capacitor is either charged or released relying upon the stage distinction between the inverter yield voltage and the AC framework voltage. Dynamic force spilling out of the AC framework to STATCOM if there should arise an occurrence of ignoring transformer obstruction is appeared in (7) [17]

(7)

In the event that α > 0, the inverter yield voltage is in stage restriction with the framework voltage. The capacitor is charged on account of P > 0. In the event that α < 0, the capacitor is released in light of P < 0. Reactive power spilling out of STATCOM to AC framework or from AC framework to STATCOM can be determined by (8)

(8)

where Vac is AC system voltage, Vstatcom is inverter output voltage, X is equivalent reactance of transformers, α is the phase difference between voltages.

In the STATCOM, the voltage Vdc is kept constant and the amplitude of the AC output voltage of the

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inverter is calculated by changing the modulation index (ma). The modulation index is usually between 0 < ma <1;

In case ma = 0.75; there is no power exchange (Vac = Vstatcom) .

In case ma = 0.65; STATCOM is in inductive mode (Vac > Vstatcom) .

In case ma = 0.85; STATCOM in capacitive mode (Vstatcom > Vac) .

Inverter output voltage in STATCOM can be calculated as shown in (9), (10):

, (9)

(10)

As indicated by (9) and (10), the yield voltage of STATCOM is balanced by keeping the DC voltage consistent and changing the mama esteem.

STATCOM works either in the capacitive or inductive mode for responsive force pay to keep the estimation of the dynamic and receptive force in the framework in network limits, and to forestall transmission misfortunes. As appeared in Fig. 3, the framework is associated straightforwardly to the reactors. In Fig. 4, a control circuit having a place with STATCOM is given and air conditioning voltage (Vbus), DC voltage (Vdc), dynamic and receptive current segments (Id&Iq) are managed and three-stage signals (Va, Vb, Vc) utilizing space vector changes (Park and Clarke) is changed over into turning pivot parts Vd and Vq. The controls are furnished with the PI regulator and STATCOM control circuit utilizing PI, PLL is displayed in Matlab/Simulink. The boundaries utilized in STATCOM is appeared in Table I.

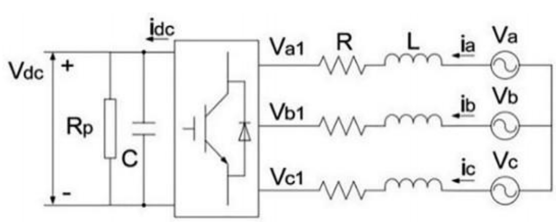

Fig. 3. The equivalent circuit of STATCOM.

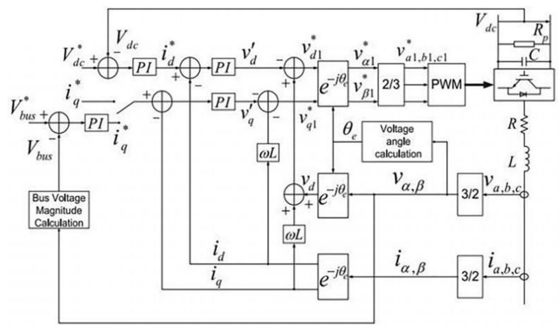

Fig. 4. STATCOM control circuit [18].

TABLE I. SYSTEM PARAMETERS OF STATCOM MODEL.

Parameter	Numerical Value
Grid line voltage	25 kV
Equivalent resistor	0.0012 Ω
Equivalent inductor	1.2 mH
Shunt capacitor	16000 µF
Capacitor voltage	2400 V
System frequency	60 Hz

The proposed hybrid framework engineering demonstrated in Simulink is appeared in Fig. 5. An appropriation framework with a 25 kV 100 MVA was utilized and lines with a length of 21 km and 2 km were utilized to send capacity to associated loads at busbar2 and busbar3, individually. A breeze turbine based twofold took care of acceptance generator was demonstrated and rotor side and network side control were performed. A backhanded MPPT strategy was utilized by wind speed and ideal force creation. A 0.4 MW PV framework was displayed and synchronization control with PLL was performed. The STATCOM was added to the point of basic coupling for decreasing the voltage vacillation toward the finish of the transport bar, and responsive force remuneration. The current, voltage, dynamic and responsive force esteems toward the finish of bus bar are initially estimated for the framework without STATCOM. A STATCOM evaluated at 3 MVAR was consolidated into the equivalent PCC for voltage guideline. In the cross breed framework with STATCOM, a variable burden between 1 MVA and 5.2 MVA was utilized toward the finish of the li ne. The STATCOM framework is customized at 1.077 p.u. to keep the reference voltage at 1 p.u.

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In this investigation, the time area measure is utilized to assess the PI regulator in the STATCOM's control circuit for voltage security. In the control framework, if the regulator tuning constants get inappropriate worth, the framework's qualities may crumble and the framework may get flimsy. Hence, ideal modification of regulator boundaries and appropriate choice of tuning constants have a significant function in the correct presentation of this control..

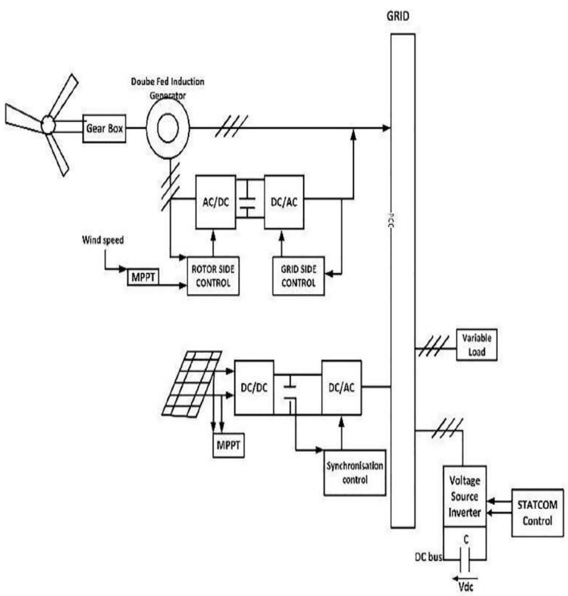

Fig. 5. Solar-wind hybrid system including STATCOM.

The most widely recognized exhibition measure is ITAE (essential outright time blunder). The impediment of the IAE (indispensable total mistake) and ISE (essential square blunder) measures is that while the minimization cycle is generally low, the transient reaction is awful. This inconvenience is tended to by utilizing ITAE or ITSE (indispensable time square mistake) [19]. In this investigation, ITAE execution measure in (11) is utilized as target work for streamlining. The consequences of the enhancement are given in Table II. Hereditary calculation codes, which are viable with the m-work code record have been composed and a decent streamlining has been completed with the right limitation, increase, change and populace size qualities. The m-work document modified in Matlab improves eight factors, advancement is done in eight-dimensional pursuit space and Kp and Ki esteems are resolved by certain lower and maximum cutoff points..

- (11)

GA based method Genetic programming begins to solve problems by applying three steps:

1. Identification of fitness function;

2. Coding (genetic coding);

3. Selecting the starting population to be random individuals.

TABLE II. CONTROLLER GAIN CONSTANTS IN STATCOM FOR ITAE.

ITAE	For AC Regulator		For DC Regulator		For (Id&Iq) current regulator	
PI constants	Kp1	Ki1	Kp2	Ki2	Kp3 Kp4	Ki3 Ki4
GA results	0.3747	0.5694	0.0114	0.8051	0.9748 0.4292	0.3043 0.7021

Redundancy is performed until an adequately decent arrangement is found and the wellness capacity of all people in the populace is determined. For the new age, the best people are chosen and intersection and change are utilized to make another age. The new age (chromosomes) is added to the populace and the best arrangement is found. Hereditary calculation is applied to locate the ideal estimation of Kp (relative) and Ki (indispensable) constants for STATCOM in ITAE as a wellness work. Kp and Ki, which are assessed by ordinary strategy, are utilized as beginning administrator for hereditary calculation. The stream graph of Fig. 6 delineates the methodology for upgrading the estimation of Kp and Ki gain constants for STATCOM utilizing GA..

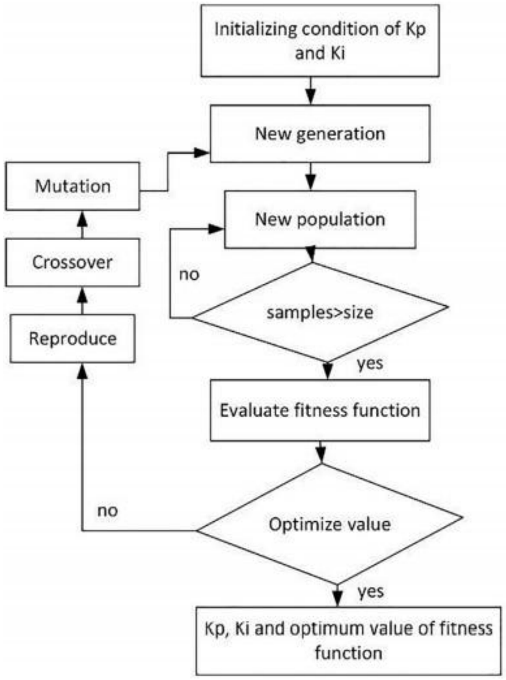

Fig. 6. Flow chart for STATCOM tuning using GA.

Particle swarm optimization

In software engineering, molecule swarm advancement (PSO) is a computational strategy that advances an issue by iteratively attempting to improve a competitor arrangement concerning a given proportion of value. It takes care of an issue by having a populace of applicant arrangements, here named particles, and moving these particles around in the pursuit space as indicated by basic numerical formulae over the molecule's position and speed. Every molecule's development is impacted by its neighborhood most popular position but at the same time, is guided toward the most popular situations in the pursuit space, which are refreshed as better positions are found by different particles. This is required to push the multitude toward the best arrangements.

PSO is a metaheuristic as it makes not many or no suppositions about the issue being streamlined and can look through exceptionally enormous spaces of up-and-comer arrangements. Notwithstanding, metaheuristics, for example, PSO don't ensure an ideal arrangement is ever found. All the more explicitly, PSO doesn't utilize the angle of the issue being enhanced, which implies PSO doesn't need that the advancement issue be differentiable as is required by exemplary improvement strategies, for example, slope plunge and semi Newton techniques..

Algorithm

An essential variation of the PSO calculation works by having a populace (called a multitude) of up-and-comer arrangements (called particles). These particles are moved around in the pursuit space as indicated by a couple of basic formulae. The developments of the particles are guided by their own most popular situation in the hunt space just as the whole multitude's most popular position. At the point when improved positions are being found these will at that point come to direct the developments of the multitude. The cycle is rehashed and by doing so it is trusted, yet not ensured, that a palatable arrangement will inevitably be found.

Officially, let f: $\mathbb{R}n \rightarrow \mathbb{R}$ is the cost work which must be limited. The capacity accepts an applicant arrangement as contention as a vector of genuine numbers and creates a genuine number as yield which shows the target work estimation of the given competitor arrangement. The inclination of f isn't known. The objective is to discover an answer a for which f(a) ≤ f(b) for all b in the inquiry space, which would mean an is the worldwide least. Amplification can be performed by thinking about the capacity h = -f.

Let S, be the quantity of particles in the multitude, each having a position xi ∈ $\mathbb{R}$n in the pursuit space and a speed vi ∈ $\mathbb{R}$n. Leave pi alone the most popular situation of molecule I and let g be the most popular situation of the whole multitude. A fundamental PSO calculation is at that point::

- For each particle i = 1, ..., S do:
  - Initialize the particle's position with a uniformly distributed random vector: $\mathbf{x}_i \sim U(\mathbf{b}_{lo}, \mathbf{b}_{up})$, where $\mathbf{b}_{lo}$ and $\mathbf{b}_{up}$ are the lower and upper boundaries of the search-space.
  - Initialize the particle's best known position to its initial position: $\mathbf{p}_i \leftarrow \mathbf{x}_i$
  - If $(f(\mathbf{p}_i) < f(\mathbf{g}))$ update the swarm's best known position: $\mathbf{g} \leftarrow \mathbf{p}_i$
  - Initialize the particle's velocity: $\mathbf{v}_i \sim U(-|\mathbf{b}_{up}-\mathbf{b}_{lo}|, |\mathbf{b}_{up}-\mathbf{b}_{lo}|)$
- Until a termination criterion is met (e.g. number of iterations performed, or a solution with adequate objective function value is found), repeat:
  - For each particle i = 1, ..., S do:
    - For each dimension d = 1, ..., n do:

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- Pick random numbers: r_p, $r_g \sim U(0,1)$
- Update the particle's velocity: $\mathbf{v}_{i,d} \leftarrow \omega\ \mathbf{v}_{i,d} + \varphi_p\ r_p\ (\mathbf{p}_{i,d}-\mathbf{x}_{i,d}) + \varphi_g\ r_g\ (\mathbf{g}_d-\mathbf{x}_{i,d})$
- Update the particle's position: $\mathbf{x}_i \leftarrow \mathbf{x}_i + \mathbf{v}_i$
- If $(f(\mathbf{x}_i) < f(\mathbf{p}_i))$ do:
  - Update the particle's best known position: $\mathbf{p}_i \leftarrow \mathbf{x}_i$
  - If $(f(\mathbf{p}_i) < f(\mathbf{g}))$ update the swarm's best known position: $\mathbf{g} \leftarrow \mathbf{p}_i$
- Now **g** holds the best found solution.

The parameters ω, φ_p, and φ_g are selected by the practitioner and control the behavior and efficacy of the PSO method.

IV. SIMULATION RESULTS:

Results with existing controllers:

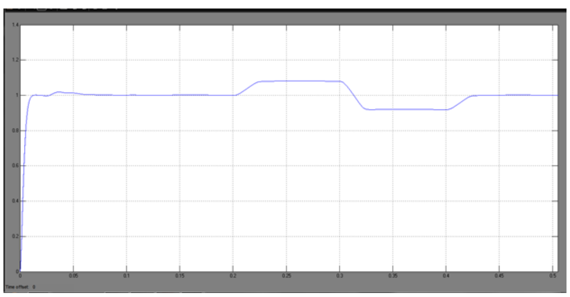


Fig. 7. Voltage profile at the end of the busbar without STATCOM

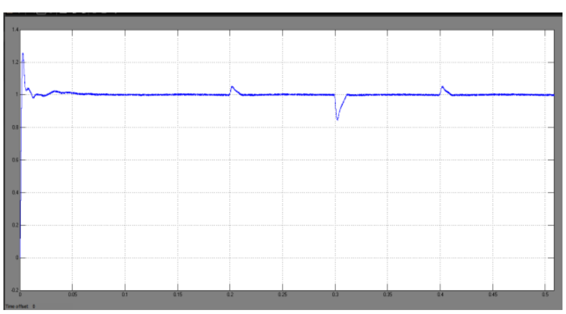


Fig. 8. Voltage profile at the end of the busbar conventional PI controller

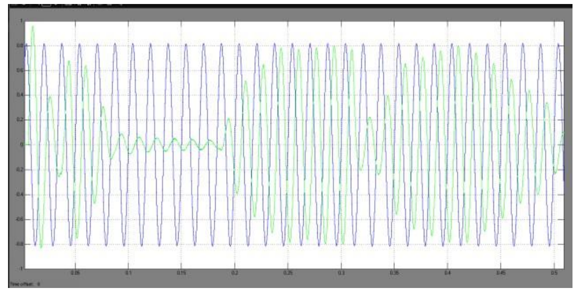
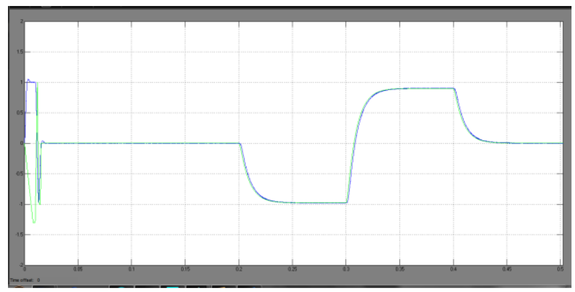
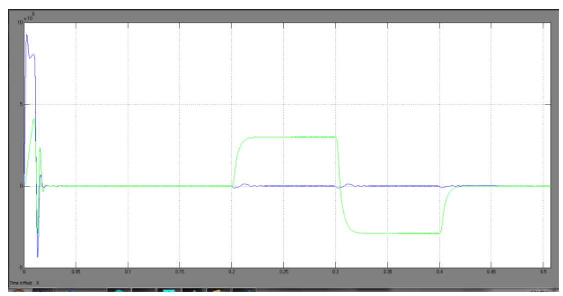


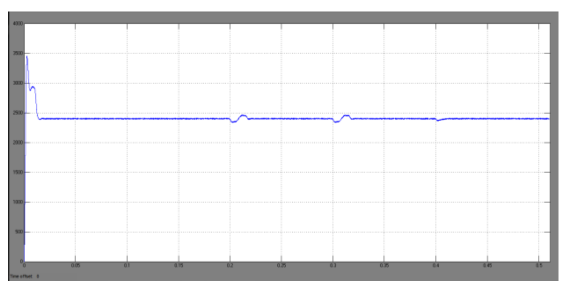
Fig. 9. (a) STATCOM output voltage profile



(b) Reactive current component of STATCOM,



(c) Produced or absorbed active and reactive power by STATCOM



(d) DC voltage.

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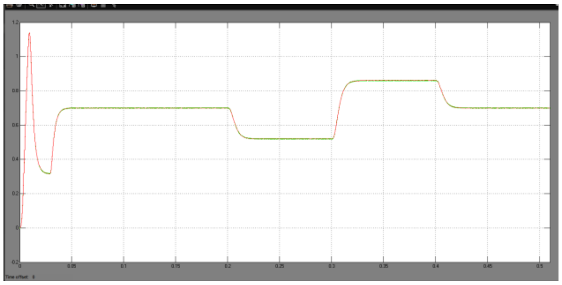
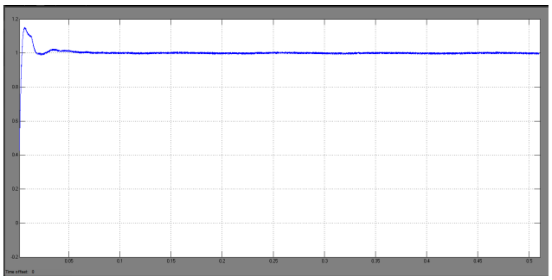


(e) Modulation index waveforms



(f) GA optimized controller, with STATCOM (p.u.)

Results with PSO controller.

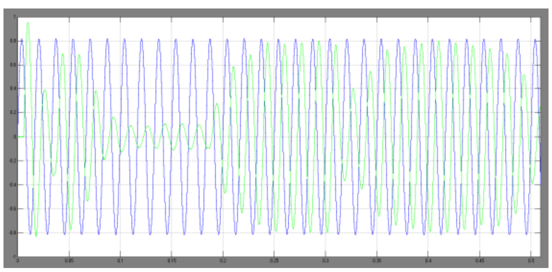
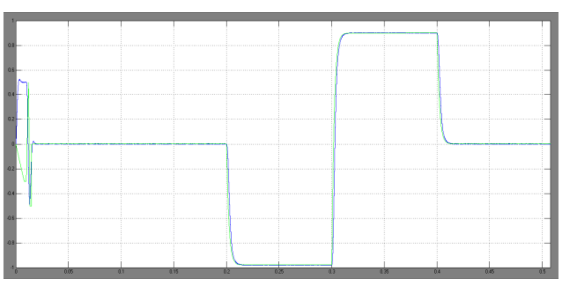
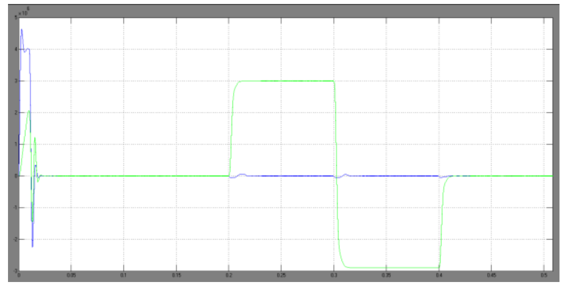


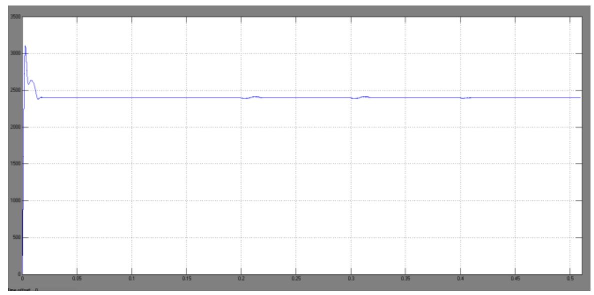
Fig.10. (a) STATCOM output voltage profile;



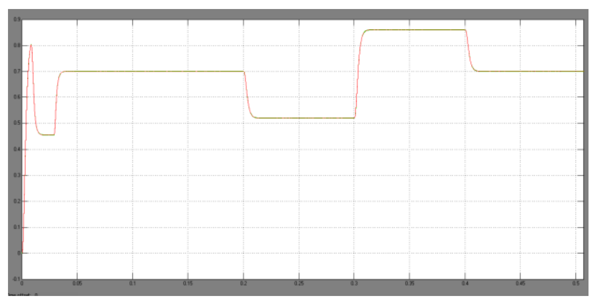
(b) Reactive current component of STATCOM,



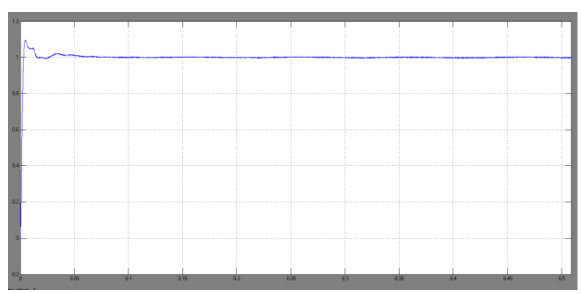
(c) Produced or absorbed active and reactive power by STATCOM,



(d) DC voltage,



(e) Modulation index waveforms.



(f) PSO optimized controller, with STATCOM (p.u.).

V. CONCLUSION:

In this examination, the effects of a 2 MW wind power enlistment generator based breeze age framework and a 0.4 MW sun based force age

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framework on the lattice was explored. For this mixture framework, it has been brought up that STATCOM gives responsive force remuneration. A sun based PV-wind power framework with a crossover structure was planned and the voltage profiles at the yield were analyzed. STATCOM was joined to examine the voltage profiles in the framework as per capacitive and responsive working states. On this premise, this work called attention to that power unsteadiness in huge transmission frameworks can be limited, and the variances brought about by the reception of sustainable power sources to the framework can be decreased. The examinations of the outcomes demonstrated that the viability of the STATCOM tuned with PSO was improved which is obviously superior to GA strategy. By getting the best qualities for PI regulator gains, voltage swell happened because of the change in receptive force has been survived and a superior powerful reaction was reached. In future investigations, distinctive other advancement procedures will be utilized to decide a more compelling one.

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