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Comparative Performance analysis of DVR & DSTATCOM for Distributed Generation with Gravitational Search Algorithm

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Abstract
The progress in the stream of the power electronic converters has led to the expansion of various protection devices for the distribution system. This also has led to an assortment of flexible transmission devices aiming to enhance the stability of the system throughout a variety of power quality issues and, furthermore, for enabling flexible uninterrupted power transmission during turbulences. This paper augments the employment of two Custom Power Devices, namely, Dynamic Voltage Restorer and Distribution Static Compensator for dealing with various power quality issues associated with distributed generation systems. This paper also involves analysis of performance of proposed Custom Power Devices with various algorithms, like gravitational search algorithm, BAT algorithm and ANT colony optimization algorithm for improving the stability of the power system. The proposed system has been tested with various distributed systems, fault conditions, and assessment has been performed among different algorithms in terms of supply voltage, supply current, active power, reactive power, and power factor. The design and analysis of entire system has been executed using MATLAB/Simulink.

Keywords
Dynamic Voltage Restorer, Distribution Static Compensator, Gravitational Search Algorithm

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УДК 004.94

Сравнительный анализ производительности DVR и DSTATCOM для распределенной генерации с алгоритмом гравитационного поиска

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Аннотация
Развитие области силовых электронных преобразователей вызвало увеличение количества защитных устройств для распределительной системы. Это привело к созданию ассортимента гибких устройств передачи, направленных на повышение стабильности системы при проблемах с качеством электроэнергии, и на обеспечение гибкой бесперебойной передачи энергии во время турбулентности. Рассмотрены возможности использования двух пользовательских силовых устройств: динамического восстановителя напряжения (Dynamic Voltage Restorer,

DVR) и распределительного статического компенсатора (Distribution Static Compensator, DSTATCOM). Применение силовых устройств предназначено для решения проблем качества электроэнергии, связанных с системами распределенной генерации. Проведен анализ производительности предложенных пользовательских устройств напряжения питания с применением алгоритмов: гравитационного поиска, летучих мышей (BAT) и муравьиного алгоритма (ANT) для повышения стабильности системы питания. Предложенная система протестирована с различными распределенными системами и условиями отказа. Выполнена оценка выбранных алгоритмов с точки зрения напряжения питания, тока питания, активной мощности, реактивной мощности и коэффициента мощности. Проектирование и анализ всей системы осуществлены с использованием пакета MATLAB/Simulink.

Ключевые слова

динамический восстановитель напряжения, распределительный статический компенсатор, алгоритм гравитационного поиска

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Introduction

The power requirement has been ever-increasing since last few years, and also still there have been numerous areas which undergo power interruptions and power disturbances tribulations. Furthermore, there has been enormous raise in the research towards the stream of power semiconductor devices which intends to condense numerous power quality troubles like voltage sag, swell, and interruptions providing continuous, stable power supply through the transmission and distribution systems. The contraption in the vicinity of semiconductor devices led to novel transmission devices well-known as Flexible AC transmission systems (FACTS), which diminishes the higher power surge, infuses the required quantity of power where the majority of the loads guzzles reducing the transient conditions and losses in the system with less cost. The FACTS devices engross the usage [1] of a variety of semiconductor devices, like thyristors, IGBT'S, GTO'S, which inject the power and also take up the power based up on the control signal provided to the switches, which also reduces the loading of lines, better flexibility for power transfer, damping out of bigger oscillations.

The custom power devices are categorized into different types, namely, static VAR compensator, static series compensator, Unified Power Flow Controller, Interline Power Flow Controller, and thyristor-controlled compensators. The series compensators holding capacitors [2] can be worn in the transmission lines which are allied in series with the lines with increased transmission capacity, higher power transfer capability, larger improvement [3] in the stability of the system, economical solution providing reduction in the generators, conductors and enlarged parallel paths for the power flow. However, the drawbacks with the series compensators are superior fault current, malfunctioning of relays, generation of larger reverse voltages across the breakers leading to the damage of the arrangement. The shunt compensators employing capacitors [4] in parallel with the lines can be utilized, which injects the reactive power during larger loading conditions and dipping the voltage drop [5] at the load side, although engage certain disadvantages like increase in the handling of generators, conductors leading to higher investment. The static var compensators supplies [6] enhanced transient stability, damping of power swings, abridged power losses, other than require larger values of inductors and capacitors. Static synchronous compensators can be equipped for lowering power quality problems which doesn't need larger passive elements, requiring smaller area and generating privileged reactive power at their output terminals. Thyristor switched capacitors [7] are one of the classifications of static var compensator utilizing thyristors whose turn 'on' and 'off' connects and disconnects the capacitor to the line thereby controlling the reactive power of the power system and acquiring benefit of advanced dynamic stability [8]. But the disadvantage of these devices is necessity of a greater number of thyristors and so increased cost of the system. So Distribution Static Compensator (DSTATCOM) is preferred as a custom power device for the power system which encompasses coupling transformer and also voltage source converter for voltage balancing for the period of abnormal conditions [9, 10]. Also, in addition to DSTATCOM, Dynamic Voltage Restorer (DVR) has been elected as one more custom device for analyzing diverse abnormal conditions and loading circumstances.

For the scheme of voltages and power at the power system, it is required to manage the converter which provides the voltage balancing; so control techniques have been adopted for the two proposed custom power devices. Control algorithms are required in power electronics for voltage generation and reference signal generation. Some control algorithms, such as Instantaneous Active-Reactive (IAR) algorithm, Synchronous Reference Frame (SRF), Unit Vector Template (UVT) generation, and Exponential Composition Algorithm (ECA). IAR and SRF are generally applied for the generation of reference signals but the drawback of IAR algorithm is the cutoff frequencies. SRF algorithm does not work well in unbalanced voltage supply. However, filtering techniques, such as high pass filter and low pass filter, is used for the extraction of DC signal [11]. UVT can be used for frequency synthesizer and it requires a Phase Locked Loop (PLL) that makes process more complex. Genetic algorithm deals effectively with many optimization problems [12] but the disadvantages with this algorithm are complicated mutation and crossover operators along with the speed of convergence. ABC algorithm can be used where honey bees moves until they attain certain optimum solution, but the disadvantages are larger objective functions [13], slower convergence speed, lower nature of exploration. Gravitational Search Algorithm (GSA) in [14, 15] uses agents as particles moving with certain velocity, it has been proposed for controlling the voltage source converter. The work utilizes GSA, Ant Colony Optimization (ACO), and BAT algorithms for the optimization of power quality. Three optimization algorithms are used to solve the optimal reactive power dispatch problem. ACO is one of the popular techniques for approximate optimization problem proposed by [16]. Real ant colonies are the inspiration source for this algorithm. Foraging behaviors of the ants are exploited in this algorithm to solve discrete optimization problems. There are several algorithms [17–19] evolved for the improvement of original ACO algorithms. BAT algorithm was introduced by [20] and it depends on the features of microbats. The DSTATCOM and DVR have been tested with three algorithms, namely, GSA, BAT, ANT algorithms for various conditions like fault occurrence, switching of synchronous generator, switching of induction generator, switching of RLC load.

DVR and DSTATCOM for dealing with power quality issues

The power system has been designed with the FACTS devices and also with various algorithms for reducing power quality issues.

DSTATCOM

This is a custom device which is designed to condense the harmonics with the switching of nonlinear loads and also reins the power factor and bus voltage with the regulation of reactive power into the lines. The one line illustration representing the static compensator with the power system is given below. It consists of grid providing supply for the loads and to the entire power system. At the load side, a wind mill with induction generator, one synchronous generator-based wind mill, one RLC load and a faulted condition have been considered and they will be switched with diverse timings. At the position of common coupling, DSTATCOM is associated which injects at the point of common coupling through coupling transformer. The basic principle in the rear of STATCOM is that it can inject or absorb the reactive power and also exchange the active power with the assist of DC source. The DSTATCOM consists of voltage source converter [1–4] coupled to the point of common coupling through transformer, and the switching for the converter will be generated with the control approach of voltage control. The DSTATCOM generates and injects reactive power at PCC acting as a capacitor if the measured voltage of the line is less in comparison with the DSTATCOM voltage. The active power exchange occurs with the faulted conditions, as soon as the voltage of the compensating device leads the supply voltage to organize [5] the voltage of the system and in addition at the voltage terminals of the DSTATCOM. When any one of the load shown in the Fig. 1 is switched to ON, power quality issues like voltage sag or swell occurs. Then that voltage magnitude is collected and evaluated with the reference voltage, and the difference is aimed towards the controller. The controller processes the error and generates gate pulses for all the six switches of the converter, which, by voltage source, injects or absorbs the required voltage and reactive power. In addition, the compensating device acts as a shunt filter which eliminates harmonic content at the load side and also at supply side.

The variables used in Fig. 1 are represented as follows: XS — Synchronous Reactance; IS — Synchronous Current; T/F — Transformer; XL — Line Reactance; IL — Line Current; S1-S6 — Switches used in DSTATCOM; CB1 — Circuit Breaker 1; CB2 — Circuit Breaker 2; CB3 — Circuit Breaker 3; CB4 — Circuit Breaker 4; SG — Synchronous Generator; IG – Induction Generator; Vref — Reference Voltage; Vabc — Three Phase Voltage.

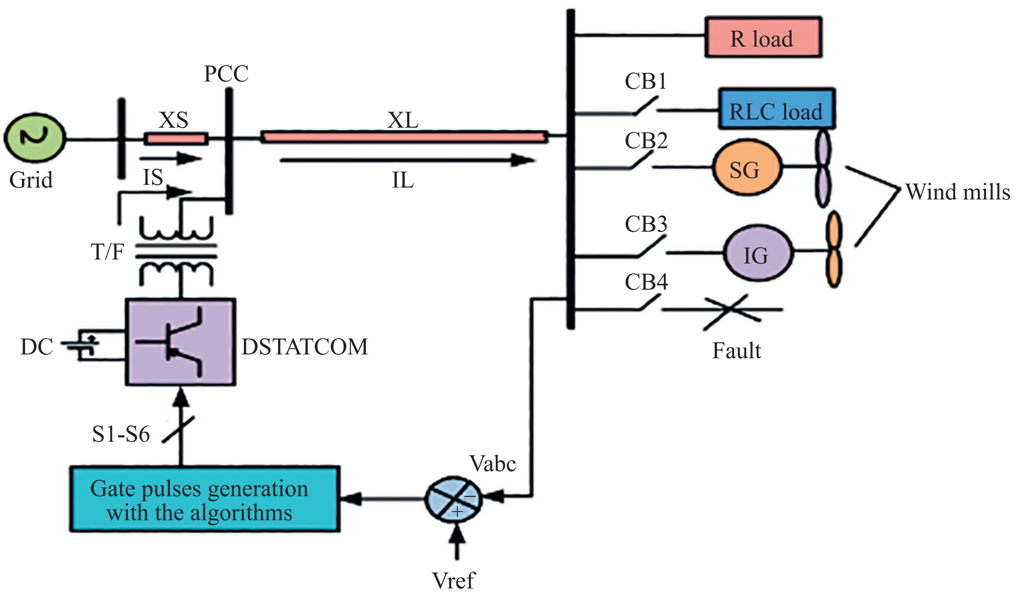

Fig. 2. One line diagram of power system with DSTATCOM

DSTATCOM equations are given as follows

$$\frac{d^i f^i}{dt} = \frac{1}{L_f}(-R_f I_{fa} + V_{ia} - V_{ta}),$$

$$\frac{d^i f^i}{dt} = \frac{1}{L_f}(-R_f I_{fb} + V_{ib} - V_{tb}),$$

$$\frac{d^i f^i}{dt} = \frac{1}{L_f}(-R_f I_{fc} + V_{ic} - V_{tc}),$$

where I_{fa}, I_{fb} and I_{fc} are the currents in the three phases of the DSTATCOM system. These currents are controlled by the VSC in order to regulate the reactive power injected by the DSTATCOM and to filter out harmonics. V_{ia}, V_{ib}, V_{ic} are the phase voltages for output and V_{ta}, V_{tb}, V_{tc} are the phase voltages in PCC bus with respect to neutral. The converter output phase voltages are

$$V_{ia} = V_{dc}U_a,$$

$$V_{ib} = V_{dc}U_b,$$

$$V_{ic} = V_{dc}U_c,$$

where, V_{ia}, V_{ib} and V_{ic} are 'switching functions' generated by Hysteresis band control method.

d^i and f^i are the current and flux variables, respectively, of the coupling transformer in the DSTATCOM system. These variables describe the magnetic field in the transformer and the current flow through it. L_f is the inductance of the coupling transformer in the DSTATCOM system. This parameter *affects the rate at which the current and flux variables change over time*. R_f is the resistance of the coupling transformer in the DSTATCOM system. This parameter affects the power losses in the transformer and the efficiency of the DSTATCOM system. U_a, U_b and U_c are the output voltage phase angles of the DSTATCOM system. These voltages are controlled by the VSC in order to regulate the reactive power injected by the DSTATCOM and to filter out harmonics. V_{dc} is the DC voltage source that powers the VSC in the DSTATCOM system. This voltage source is typically derived from a capacitor or battery bank, and its value affects the overall power capacity and efficiency of the DSTATCOM system.

DVR

The DVR is a custom device regulating harmonics at the side of source voltage and also managing the enormity of voltages. It is essentially employed for the voltage sag mitigations at the supply side. It is identical to static compensator comprising of voltage source converter and a transformer, but the difference is that the transformer is connected in series with the distribution system and load as shown in Fig. 2. So, a DVR [6] is a power electronic converter utilizing gate turnoff thyristor or insulated gate bipolar transistor as a toggle with the DC supply and injection transformer. Three single phase transformers [7] are coupled in series through the line to couple the voltages into the system. It controls as well the active power and reactive power by absorbing or injecting into the line for a very slighter duration of milliseconds. It injects voltage in series with the line with injection transformer [9] by means of forced commutated converter. Furthermore, with the help of transformer, the restorer can be isolated from the system at any period of time. Underneath normal operating conditions, as the error between the reference voltage and actual voltage is very little, converter injects very little voltage compensating the device losses. Beneath power quality issue like voltage sag occurrence, as the error will be extremely larger value, it generates larger voltage in series with the line with controlled magnitude and phase angle. GSA, ACO and BAT algorithms are utilized in the work to identify the optimal settings of RLC load and to minimize the voltage stability of all the load buses. Parameters, such as L-Index, voltage error/deviation Extra High Voltage (EHV), are calculated to improve the voltage profile and voltage stability.

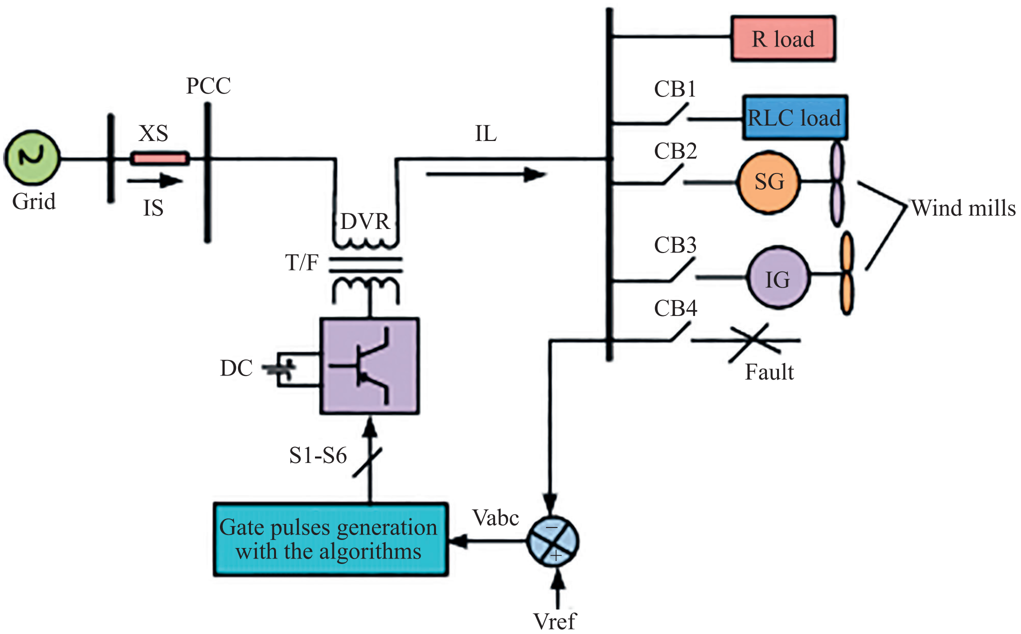

Fig. 2. One line diagram of power system with DVR

Proposed GSA for controlling the FACTS devices

GSA

This algorithm is an optimization method based on the Netwon's law of gravity and associated interactions of masses. It represents the interactions among the number of agents by the force of gravity.

It employs agents which are acknowledged as objects and whose performance will be deliberated by their inertial and gravitational masses which are also identified as solutions. The heaviest mass represents the optimum solution and the remaining lightest masses get attracted towards the heaviest mass. Because the heavier masses have greater fitness values, they represent good solution for the problem and it works slowly during worse solutions. Therefore, effective configuration can be obtained using GSA in the optimization of power quality issues. This GSA [11] is a heuristic method which depends on the law of gravity and law of motion. According to the principle of gravity law, one particle exerts force on other particle due to force of attraction [12, 13] or repulsion. That force exertion can be distinguished as the product of gravitational constant and fraction of two masses with the square of distance between the two masses [14]. The force of attraction or repulsion of one mass on other mass can be expressed as

$$F = G\frac{M_1M_2}{R^2},$$

where F is the force of one mass on other mass; M_1M_2 are the masses of two particles; R is the distance between the two particles; G is the gravitational constant which is a fundamental constant of nature that determines the strength of the gravitational force.

The GSA also obeys the law of motion which states that the velocity of any particle depends on the previous state of velocity with certain change in time. The variation in the velocity with respect to time is also known as acceleration which is defined in [15] as the force acting up on the masses of the particles and can be expressed as

$$a = \frac{F}{M}.$$

Consider a system consisting of n number of particles with their respective masses, the location of the i-th particle can be given as

$$X_i = (x_i^1, x_i^2, x_i^3, \ldots, x_i^n),$$

where x_i^d is the location of the i-th particle in the d-th dimension and n is the dimension of search space. At a precise time period of t, the force acting on the particle i from particle j can be given as

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)M_{aj}(t)}{R_{ij}(t) + \in},$$

where $M_{aj}(t)$ is the gravitational mass linked to the particle j in period of t; $M_{pi}(t)$ is the inactive gravitational mass associated to the particle i; $G(t)$ is gravitational constant at a period of t; $R_{ij}(t)$ is the Euclidian distance between particles i and j; and $\in$ is a small constant to prevent division by zero in case the two particles are at the same location. Here, particles are considered as objects whose performance is represented by their feature of masses. The flow chart for the GSA is given below.

The following are the steps for the working of GSA on the power systems as shown in Fig. 3.

— The initial numbers of agents are considered and positions are identified with the initial population.
— The fitness of all the particles are determined to find the best and worst fitness among all the particles either by applying maximization or minimization principle.
  Minimization problem:
  Pbest (t) = max fit$i(t)$, $j \in \{1, 2,\ldots, N\}$
  Worst (t) = max fit$i(t)$, $j \in \{1, 2,\ldots, N\}$.
  Maximization problem:
  Best (t) = max fit$j(t)$, $j \in \{1, 2,\ldots, N\}$
  Worst (t) = min fit$j(t)$, $j \in \{1, 2,\ldots, N\}$.
— At iteration of period t, the gravitational constant is updated by the following equation

$$G(t) = G_0 e^{\frac{-at}{T}},$$

where, G_0 represents the initial value of the gravitational constant and T is the maximum number of iterations

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)M_{aj}(t)}{R_{ij}(t) + \in}(x_j^d(t) - x_i^d(t)).$$

Euclidian distance among two particles i and j could be given by:

$$R_{ij}(t) = \|R_i(t) \times R_j(t)\|.$$

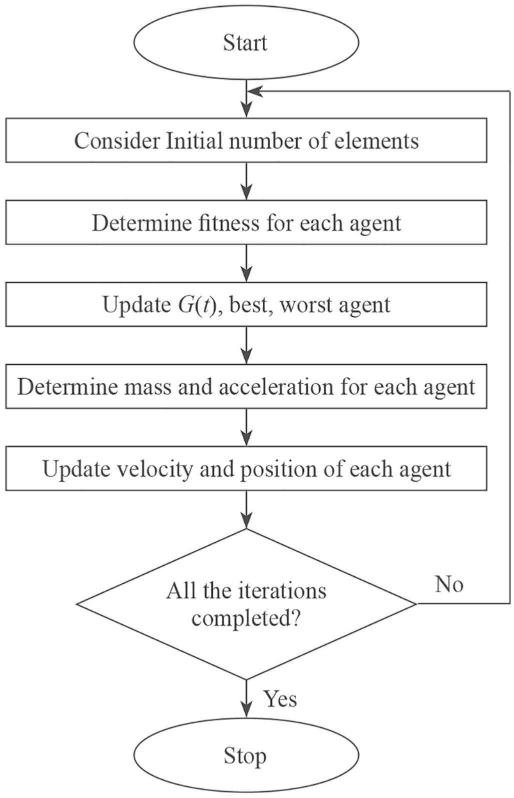

Fig. 3. Flowchart of GSA algorithm

— The total force on particle i at iteration period of t can be given as

$$F_i^d(t) = \sum rand_j F_{ij}^d(t).$$

– Depending on the best and worst values, the gravitational and inertia masses are calculated for each particle and can be given as

$$M_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)},$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1 \text{ to } n} m_j(t)}.$$

— After the calculation of masses, the acceleration of thei-th particle at iteration t is determined as

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)}.$$

— Then the velocity and the position of each particle i at next iteration $(t + 1)$ is updated.

$$vi(t + 1) = \text{rand}i \times vi(t) + ai(t),$$
$$xi(t + 1) = xi(t) + vi(t + 1).$$

— Repeat the process by increasing the iteration counter until the termination criteria set at beginning are satisfied and consider the best optimal of all iterations as the optimal solution of the algorithm.

Discussion of Results

The simulation of the proposed power system with two FACTS devices, namely, DSTATCOM, DVR has been implemented with various test cases like switching on of loads, occurrence of fault conditions and controlled with three algorithms, namely, GSA, ACO, BAT.

DVR in Power System

The power system has been simulated with grid at source side and load at the end side, and the waveform in Fig. 4 show the PCC parameters at rated value where (and later on the graphs legend) I represents current, V represents voltage, P represents active power and Q represents reactive power.

The Table 1 shows the rated parameters of the power system.

With fault condition in the power system. The LLL (3-Line) fault has been created in the system at $t = 0.1$ s to $t = 0.65$ s, and various algorithms have been tested for DVR.

The voltage has been almost remained constant, current has been increased by 26 times from the rated value, active power has been increased by 7 times from the rated value and reactive power is almost zero as shown in Fig. 5.

GSA. This algorithm has been used for the DVR and the waveforms below show the PCC parameters under faulted conditions with DVR.

The voltage has been almost remained constant, current has been maintained at 3.5 times of the rated value, active power has been maintained at 3.5 times of the rated value and reactive power is almost zero, as shown in Fig. 6.

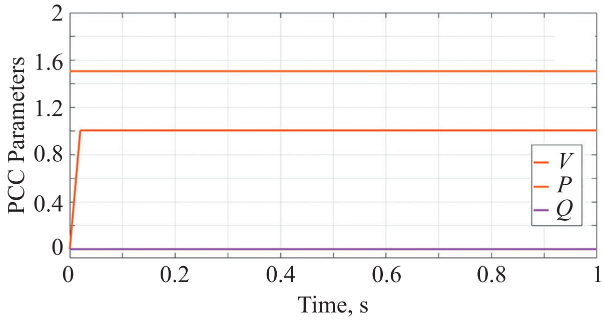

Fig. 4. PCC Parameters of power system

Table 1. PCC Parameters of power system

Parameter, pu	Rated values
Voltage	1
Current	1
Active power	1.5
Reactive power	0
Power factor	1

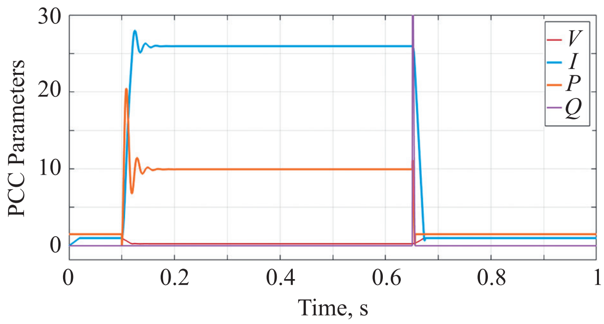

Fig. 5. PCC Parameters of power system under faulted condition

Table 2 represents the various parameters observed for different algorithms at PCC.

With wind based synchronous generator. The wind turbine based synchronous generator has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DVR.

The voltage has been almost remained constant, current has been increased to 0.3 times of the rated value, active

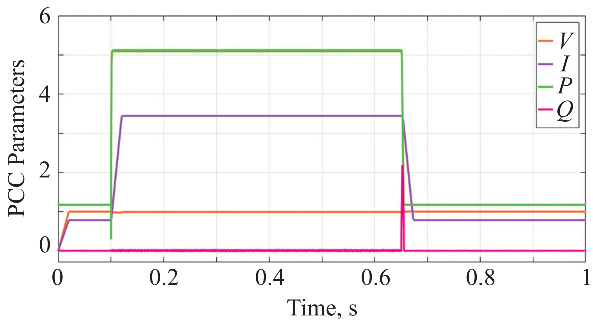

Fig. 6. PCC Parameters of power system under faulted condition after applying DVR and GSA

Table 2. PCC Parameters with fault for GSA, BAT, ANT algorithms

Parameter, pu	Without FACTS devices	GSA	BAT	ANT
Voltage	0.256	0.989	0.990	0.99
Current	25.900	3.440	2.974	2.99
Active power	10	5.140	4.460	4.54
Reactive power	0	0.040	0.042	0.05
Power factor	0.990	0.999	0.900	0.99

power has been increased to 0.3 times of the rated value and reactive power has been increased to 0.4 pu, as shown in Fig. 7.

GSA. This algorithm has been used for the DVR and the waveforms below show the PCC parameters with connection of wind turbine based synchronous generator with DVR.

The voltage has been almost remained constant, current has been reduced to 0.11 times of the rated value, active power has been reduced to 0.11 times of the rated value and reactive power has been reduced to 0.23 pu as shown in Fig. 8, and in Table 3 represents the various parameters observed for different algorithms at PCC.

With wind based induction generator. The wind turbine based induction generator has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DVR.

The voltage has been almost remained constant, current has been increased to 2 times of the rated value, active power has been maintained at rated value with oscillations and reactive power has been increased to 2.45 pu, as shown in Fig. 9.

GSA. This algorithm has been used for the DVR and the waveforms below show the PCC parameters with connection of wind turbine based induction generator with DVR.

The voltage has been almost remained constant, current has been reduced to 1.3 times of the rated value, active power has been reduced to 0.16 times of the rated value and reactive power has been increased to 1.2 pu, as shown in Fig. 10. Table 4 represents the various parameters observed for different algorithms at PCC.

With RLC load. The RLC load has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DVR.

The voltage has been almost remained constant, current has been almost remained constant, active power has been increased to 0.02 times of the rated value and reactive power has been almost remained constant at zero as in Fig. 11.

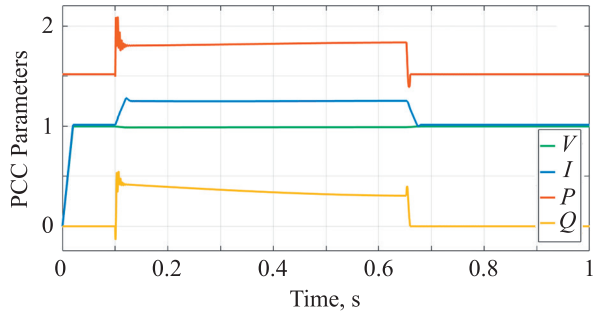

Fig. 7. PCC Parameters of power system with synchronous generator

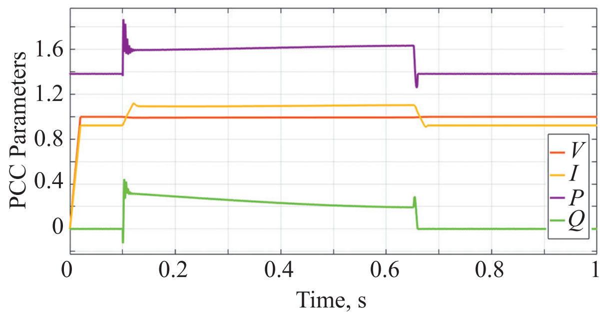

Fig. 8. PCC Parameters of power system with synchronous generator after applying DVR and GSA

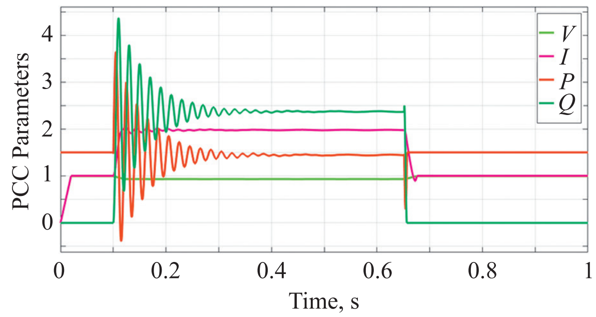

Fig. 9. PCC Parameters of power system with induction generator

Table 3. PCC Parameters with synchronous generator for GSA, BAT, ANT algorithms

Parameter, pu	Without FACTS devices	GSA	BAT	ANT
Voltage	0.980	0.992	0.989	0.989
Current	1.249	1.093	1.167	1.168
Active power	1.810	1.620	1.696	1.700
Reactive power	0.400	0.315	0.360	0.350
Power factor	0.980	0.980	0.970	0.980

Table 4. PCC Parameters with induction generator for GSA, BAT, ANT algorithms

Parameter, pu	Without FACTS devices	GSA	BAT	ANT
Voltage	0.935	0.97	0.9685	0.968
Current	1.212	1.3	1.385	1.4
Active power	2.4	1.6	1.660	1.6
Reactive power	1.5	1.07	1.180	1.2
Power factor	0.935	0.83	0.810	0.815

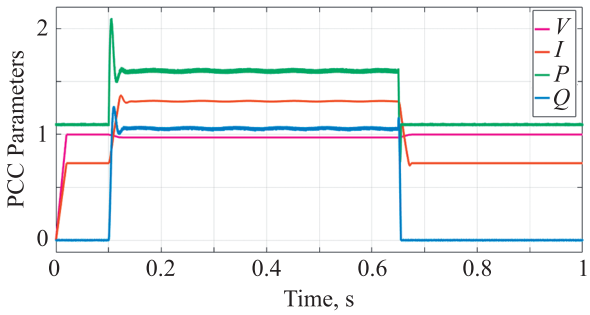

Fig. 10. PCC Parameters of power system with induction generator after applying DVR and GSA

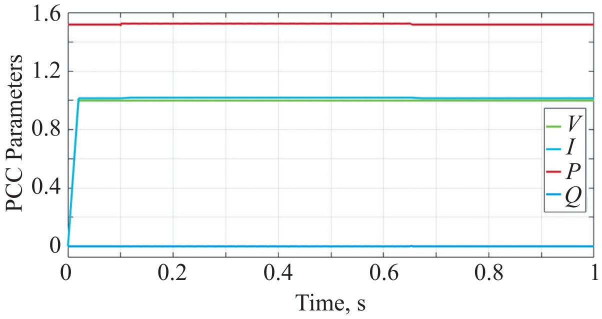

Fig. 11. PCC Parameters of power system with RLC load

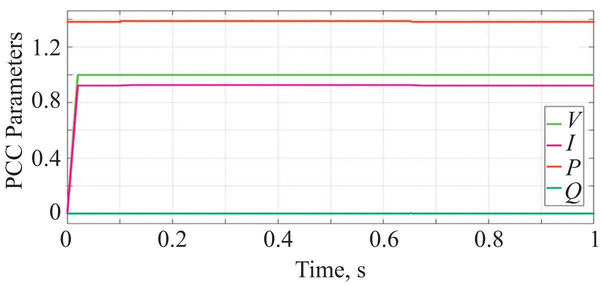

Fig. 12. PCC Parameters of power system with RLC load with DVR and GSA

GSA. This algorithm has been used for the DVR and the waveforms below show the PCC parameters with connection of RLC load with DVR.

The voltage has been almost remained constant, current has been reduced to 0.92 pu, active power has been reduced to 1.399 pu and reactive power has been almost remained constant at zero as shown in Fig. 12. Table 5 represents the various parameters observed for different algorithms at PCC.

DSTATCOM

The power system has been simulated with grid at source side and load at the end side and the waveforms below show the PCC parameters at rated values.

With fault condition in the power system. The fault has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DSTATCOM.

GSA. This algorithm has been used for the DSTATCOM and the waveforms below show the PCC parameters with occurrence of fault with DSTATCOM.

As per the Fig. 13, the voltage has been almost remained constant, current has been maintained at 7.7 times of the rated value, active power has been maintained at 4.2 times of the rated value and reactive power is almost zero. Table 6 represents the various parameters observed for different algorithms at PCC.

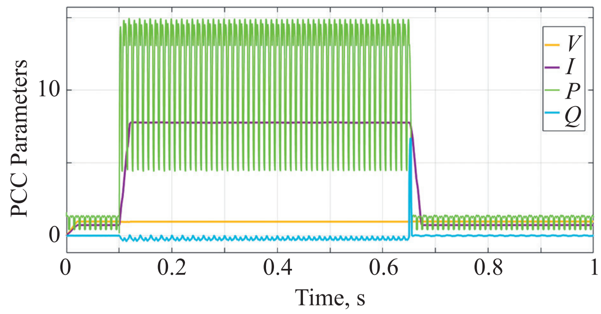

Fig. 13. PCC Parameters of power system under fault condition after applying DSTATCOM and GSA

Table 5. PCC Parameters with RLC load for GSA, BAT, ANT algorithms

Parameter, pu	Without FACTS devices	GSA	BAT	ANT
Voltage	0.998	0.998	0.998	0.998
Current	1.018	0.9255	0.926	0.920
Active power	1.526	1.390	1.391	1.400
Reactive power	0.0001	0.0037	0.0005	0.0003
Power factor	0.999	0.990	0.990	0.990

Table 6. PCC Parameters with fault for GSA, BAT, ANT algorithms

Parameter, pu	GSA	BAT	ANT
Voltage	0.950	0.960	0.6
Current	7.780	7.780	4.9
Active power	14.900	1	5.1
Reactive power	0.002	0.0037	0.0037
Power factor	0.946	0.940	0.99

With wind based induction generator. The wind turbine based induction generator has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DSTATCOM.

GSA. This algorithm has been used for DSTATCOM and the waveforms below show the PCC parameters with connection of wind based induction generator using DSTATCOM.

The voltage has been almost remained constant, current has been maintained at 7 times of the rated value, active power has been maintained at 4 times of the rated value and reactive power is increased to 1.8 pu as shown in Fig. 14. Table 7 represents the various parameters observed for different algorithms at PCC.

With wind based synchronous generator. The wind turbine based synchronous generator has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DSTATCOM.

GSA. This algorithm has been used for the DSTATCOM and the waveforms below show the PCC parameters with connection of wind based synchronous generator using DSTATCOM.

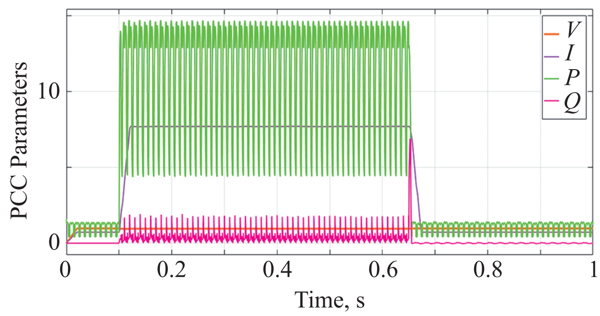

Fig. 14. PCC Parameters of power system with induction generator condition after applying DSTATCOM and GSA

Table 7. PCC Parameters with induction generator for GSA, BAT, ANT algorithms

Parameter, pu	GSA	BAT	ANT
Voltage	0.952	0.953	0
Current	7.695	7.7	3.5
Active power	14.670	14.6	5
Reactive power	1.8	2	1
Power factor	0.950	0.9	0.95

As in Fig. 15, the voltage has been almost remained constant, current has been maintained at 7.4 times of the rated value, active power has been maintained at 4 times of the rated value and reactive power is increased to 7.4 pu. Table 8 represents the various parameters observed for different algorithms at PCC.

With RLC load. The RLC load has been connected to the system at $t = 0.1$ s to $t = 0.65$ s and various algorithms have been tested for DSTATCOM.

GSA. This algorithm has been used for the DSTATCOM and the waveforms below show the PCC parameters with connection of RLC load using DSTATCOM.

The voltage has been almost remained constant, current has been maintained at the rated value, active power has been maintained at 1.2 times of the rated value and reactive power is maintained at zero pu.as shown in Fig. 16. Table 9 represents the various parameters observed for different algorithms at PCC.

The DSTATCOM and DVR have been tested with three algorithms, namely, GSA, BAT and ANT algorithms for various conditions like fault occurrence, switching of

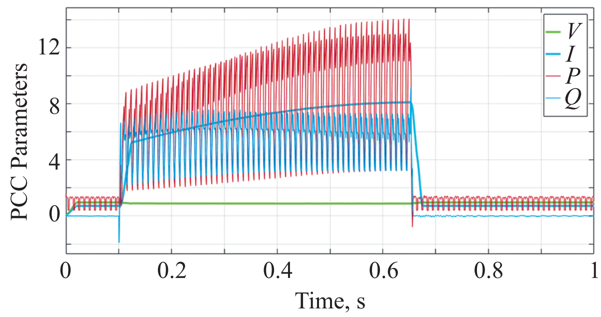

Fig. 15. PCC Parameters of power system with synchronous generator after applying DSTATCOM and GSA

Table 8. PCC Parameters with synchronous generator for GSA, BAT, ANT algorithms

Parameter, pu	GSA	BAT	ANT
Voltage	0.88	0.89	0.59
Current	7.30	5.20	2.70
Active power	12.10	8	1.80
Reactive power	7.40	7.10	3
Power factor	0.70	0.60	0.38

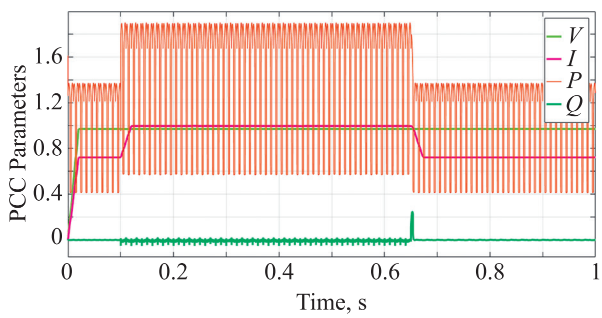

Fig. 16. PCC Parameters of power system with RLC load after applying DSTATCOM and GSA

Table 9. PCC Parameters with RLC load for GSA, BAT, ANT algorithms

Parameter, pu	GSA	BAT	ANT
Voltage	0.970	0.970	0.610
Current	0.998	0.990	0.630
Active power	1.9	1.9	1
Reactive power	0	0.0037	0
Power factor	0.920	0.926	0.975

synchronous generator, switching of induction generator, switching of RLC load where at every case DVR shows the better performance with GSA than DSTATCOM with comparison of remaining two algorithms.

Conclusions

The analysis of performance of DVR, DSTATCOM with various algorithms, like GSA, BAT and ANT, has been presented in this paper. The modeling is done using MATLAB/ Simulink for solving the power quality issues like sag and swell. Three phase fault and external signal are implemented for the analysis of voltage sag and swell. The proposed system has been tested with switching of synchronous generator, induction generator, RLC load and occurrence of fault condition, and comparison has been performed among various algorithms in terms of supply voltage, supply current, active power, reactive power and power factor where DVR shows the better performance with GSA than DSTATCOM with comparison of remaining two algorithms by 5 %. In future, we plan to implement deep learning strategies and hybrid approaches to enhance the scalability of the power systems.

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