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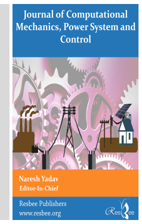

Improved Shuffled Jaya Algorithm: Advancement of LVRT Capacity of PV-Array using MPPT Algorithm

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Abstract: Wind Turbine (WT) has become an acceptable replacement for electricity production by enormous financial and environmental compensations by fossil or nuclear power plants. Nowadays various researchers are working in this field to propose the WT performance to the Doubly Fed Induction Generator (DFIG)- Low Voltage Ride Through (LVRT) system with maximum increase as well as flexibility. In order to conquer the characteristics of non-linearity of WT, exploiting Maximum Power Point Tracking (MPPT) algorithm, the PV array is operated which is involved beside with the WT to enhance system performance. For the DFIG-LVRT system, this work proposes to experiment with the Control System (CS) which plays an important role in the experimentation of controllers to correct error signals. In this research, a new algorithm named Improved Shuffled Jaya Algorithm (IS-JA) by means of fuzzified error model to experiment optimized CS. Moreover, it differentiates the proposed model-based LVRT system by means of the conventional LVRT system as well as system by means of the least increase, utmost increase. Furthermore, the developed model is evaluated concerning the conventional models, and it also states that the results in terms of the quantitative analysis. In addition, quantitative analysis is carried out which presents the estimation of Root Mean Sqaure Error (RMSE) with altering speed. Hence, the proposed model is shown that its performance is better than conventional models.

Keywords: Control System, LVRT, MPPT, RMSE, Wind Turbine.

Nomenclature

Abbreviations	Descriptions
GSC	Grid-Side Converter
eFPA	Economic Dispatch Euclidean Affine Flower Pollination Algorithm
SCIG	Squirrel Cage Induction Generator
WTG	Wind Turbine Generator
GSA	Gravitational search algorithm
HEMS	Home Energy Management System
PDF	Probability Distribution Function
BFPA	Binary Flower Pollination Algorithm
VSC	Voltage Source Converter
CI	Computational Intelligence
MPPT	Maximum Power Point Tracking
GA	Genetic Algorithm
CSG	Control Signal Generator
MCS	Monte-Carlo simulation
BESS	Battery Energy Storage System
MINLP	Mixed Integer Nonlinear Programming
RNS	Reactive Neural System
LVRT	Low Voltage Ride Through
WECS	Wind Energy Conversion System
THD	Total Harmonic Distortion
VFC	Variable Frequency AC/DC/AC Converter
DFIG	Doubly fed induction generator
RSC	Rotor-Side Converter
PV	Photo-Voltaic
CEED	Combined Emission Economic Dispatch

1. Introduction

The increasing utilization of fossil-based energy resources requires a persistent try to find replacement resources. Because of the ecological causes renewable energy resources which considered superior options [1]. Wind energy and solar photovoltaic are considered as one the hopeful as well as practicable sources it is extensively called that wind as well as solar energy resources are not at all concluding their alteration into power are without pollution and their convenience is furthermore at no cost. In environmental contamination, the important problem for humanity is maximizing. Subsequent to the identification of substitute resources of electricity production sources the wind energy as well as the solar photovoltaic system which turns out to be rising highly renowned. For the global case, there is a small indication that instantly needed to alter, the fossil fuels era which is an extensive manner to over. Nevertheless, their importance is still minimized nevertheless it is not reasonable to remain for considering action over movement included in weather changes. Globally, governments possess initiated to transfer their rules and regulations to aid renewable energy resources consumption by involving the condition of enhancing ability of renewable energy resources as well as energy conservation scheme. To present the reliable as well as constant energy supply as wind energy as well as solar photovoltaic energy resources turns out be difficult, which are dependent on whether circumstances [2]. These problems can be understood using a logical energy storage collection besides wind and solar photovoltaic energy resources [3].

DFIG is considered as a well known wind turbine that involves an induction range with a slip range. Since the 20th century, wind power is the highly quickly increasing because of its resourceful, reproducible as well as contamination-free characteristics. During transient as well as normal operations faults with higher penetration in the grid, wind energy has an improved effect on dynamic power system behavior. In the stability problems, nowadays this brought novel issues and hence the work of wind power influence on power system transient stability has to turn out to be significant problems. A few **y**ears before, one of the general kind of generators exploited the WECS was the SCIG, a fixed speed WTG system that possesses numerous disadvantages [4].

Many disadvantages can be eradicated while variable speed WTGs are exploited. In power electronic by means of up-to-date development, a wind turbine with DFIG has received huge concentration. At the stator terminals, the induction generator is grid-connected and at rotor mains through a partially rated VFC in the DFIG. Using a dc-link capacitor, VFC comprises a GSC and RSC linked back-to-back. The generator is fully controlled by the VFC namely decoupled control of reactive as well as active power, more rapidly dynamic response with minimum harmonic distortion, etc, small fraction of total power is only handled [5]. The system effectuality is improved by the DFIG with its best mechanical stresses, rotational speed, minimizes noise enhances the quality of power, and recompense for torque and power pulsations. RSC of DFIG might be blocked at the time of a grid fault, while linked to the grid to secure it from unconditional current in the motor circuit. The wind turbine expeditions in a while subsequent to the converter were blocked [11]. Nevertheless, subsequent to the fault clearance, it repeatedly re-links itself to the power network. From the power network, RSC will not restart, and then the wind turbine is disconnected. This presents a voltage instability risk. It is, therefore, dangerous to control voltage stability to control uninterrupted DFIG wind turbines operation [12].

The main contribution of this research is to propose a novel model named IS-JA technique to experiment with an optimized Control System for DFIG-LVRT system using MPPT model with WT for PV array. Moreover, it differentiates IJSA based LVRT system from the conventional LVRT system as well as the model with the least increase, utmost increase. Finally, the proposed model is evaluated with conventional models to prove its efficiency.

2. Literature Review

In 2014, Arunava Chatterjee et al [1], proposed an enhanced control method. An inverter with PV panels was exploited to control the excitation and was also provides the power to the DC bus. The generator was enabled by the developed model to build up the voltage from minimum wind speeds which was evaluated with the existing three phase machines. Here, GSA was exploited to compute the switching angles of the inverter in several loads and wind speeds for the smallest amount THD of the generated voltage.

In 2018, Faizan A. Khan et al [2], focused on hybrid energy systems on the basis of solar PV and wind resources. Moreover, this work highlights several metrics of economic feasibility, sizing schemes with logical developments to improve their consumption, further prediction, and their collection. Here, schemes to model an effective storage system were shown.

In 2017, C. Shilaja and K. Ravi [3], developed a novel method based on CEED for PV panels and thermal power generation units. In order to improve the eFPA and BFPA was employed to resolve optimization problem for 20 PV and five thermal generators were carried out by means of full solar radiation and with minimized solar radiation in the CEED method.

In 2018, Reza Hemmati [4], presented HEMS involves BESS, load limitation choice, small-scale wind turbine, as well as fuel cell vehicle. The developed HEMS were stated as an MINLP and resolved using the cultural technique as an effectual Meta-heuristic optimization technique. All three operating circumstances were exploited for home. Using Gaussian PDF and MCS the output power of the wind unit was designed and also applied to deal with uncertainties.

In 2015, Adam Chehouri et al [5], developed an examination of optimization models and schemes used to the performance of wind turbine optimization. The paper was analyzed by identifying the majority of important objectives, targets as well as problems, and the optimization formulations, strategies, and models present in the state-of--the-art. The present energy demand integrated with fossil-fuel reserves depletion and stricter environmental regulations have tended to the advancement of substitute renewable energy solutions such as wind energy.

3. MPPT algorithm for PV Array System

The hybrid integrated strategies is comprised of three modules, the modelling, and control strategies, are described as follows [6]

3.1 Photovoltaic system

It residuals as one of the important forms for exhibiting performance of PV modules in diverse circumstances is single diode model. The model for combined DFIG as well as PV array is stated in [7], on the basis of this model, the relation between PV module output voltage as well as current is stated in Eq. (1). Here, V as well as I signifies output voltage as well as current correspondingly, I_s signifies diode dark current, I_{ph} signifies the photocurrent of cell that are linked directly to irradiation stage, N_s signifies the number of series-linked cell in a module, a signifies quality factor of the diode, V_t signifies cell semiconductor's thermal voltage and R_s as well as R_p signifies series and parallel resistance of a cell, correspondingly.

$$I = I_{ph} - I_s\left(\exp\left(\frac{R_s I + V}{N_s a V_t}\right) - 1\right) - \frac{R_s I + V}{R_p} \tag{1}$$

Eq. (2) states a common model for operating I_s on the basis of datasheet factors and module temperature factors. Here, I_{SCn} as well as V_{OCn} signifies short circuit current and open-circuit voltage at irrelevant circumstances on the basis of the module datasheet, K_i and K_v indicates current and voltage parameters for temperature, as well as T_c and T signifies functioning of nominal temperature and cell correspondingly.

$$I_s = \frac{K_i(T - T_c) + I_{SCn}}{\exp\left(\frac{K_v(T - T_c) + V_{OCn}}{N_s a V_t}\right) - 1} \tag{2}$$

3.2 MPPT algorithm

In [8], the methodical model for subsequent the appropriate MPP in different irradiations calculates MPP based on module formulation and features. Hence, to examine the PV output array there is no condition to pursue MPP. Eq. (3) signifies the relation between module output voltage as well as current with power obtained by multiplying Eq. (1) by V is shown.

$$P = V \times \left(I_{ph} - I_s\left(\exp\left(\frac{R_s I + V}{N_s a V_t}\right) - 1\right) - \frac{R_s I + V}{R_p}\right) \tag{3}$$

Power is derived concerning MPP voltage needs to be zero. As a result, on basis of Eq. (3), from Eq. (4) MPP can be attained.

$$I_m = V_m \frac{\frac{I_s}{N_s a V_t}\exp\left(\frac{R_s I_m + V_m}{N_s a V_t}\right)}{1 + R_s \frac{I_s}{N_s a V_t}\exp\left(\frac{R_s I_m + V_m}{N_s a V_t}\right)} \tag{4}$$

By paying no attention to the series of resistances Eq. (4) becomes Eq. (5), that V_{mi} and I_{mi} signifies output voltage as well as the current of an ideal MPP cell.

$$I_{mi} = V_{mi} \frac{I_s}{N_s a V_t} \exp\left(\frac{V_{mi}}{N_s a V_t}\right) \quad (5)$$

At present, by paying no attention to the series of resistances in Eq. (1) as well as inscribing it at MPPT, Eq. (6) is devised.

$$I_{mi} = I_{ph} - I_s\left(\exp\left(\frac{V_{mi}}{N_s a V_t}\right) - 1\right) \quad (6)$$

From Eq. (6), substitute I_{mi} value in Eq. (5) as well as carried out specific numerical configurations attains Eq. (7).

$$\left(1 + \frac{V_{mi}}{N_s a V_t}\right) \exp\left(\frac{V_{mi}}{N_s a V_t}\right) = \frac{I_{ph} + I_s}{I_s} \quad (7)$$

Finally, on the basis of eq. (7), a methodical solution to measure V_{mi} in the ideal cell is stated in Eq. (8), in which $W(x)$ signifies Lambert *W* operation that is inverse of the Eq. (9).

$$V_{mi} = N_s a V_t W\left(\frac{I_s + I_{ph}}{I_s} e\right) - N_s a V_t \quad (8)$$

$$y = x.e^x \quad (9)$$

Eq. (8) is computed as V_m with acceptable accuracy. Nevertheless, to attain maximum efficiency, by combining the series resistance's series as in Eq. (8), the final configuration to evaluate MPP can be attained as stated in Eq. (10).

$$V_m = R_s\left(I_{ph} - I_s\left(\exp\left(\frac{V_{mi}}{N_s a V_t}\right) - 1\right)\right) + V_{mi} \quad (10)$$

I_{ph} can be attained from Eq. (1), by computing the current as well as voltage at a few functioning points. Here, the sequence of parallel resistance was not considered.

3.3 Photovoltaic Module Control

An enhanced converter switching is synchronized using two models [7]. At first, V will be differentiated with an orientation value, and then an equivalent current will be generated. With the actual current system, the generated reference current is differentiated using the PI controller; for the converter switching parameter, the final value will be generated. Despite the declaration that this method assures maximum performance, it would cost a supplementary current sensor. Furthermore, the strategy developed is a voltage regulation that is very easy. Accordingly, Fig. 1 demonstrates the control framework of the PV system.

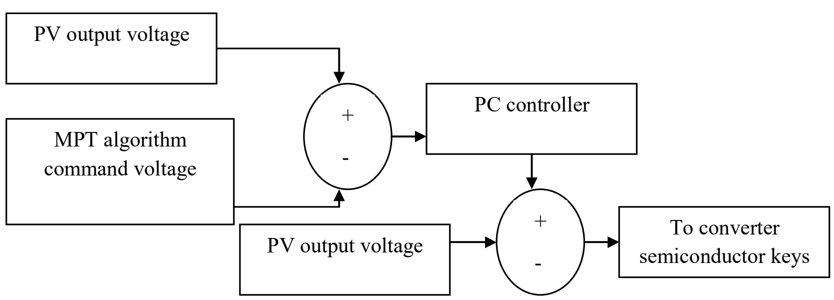

Fig. 1. *Contol model of PV array*

4. Developed Control Model for DFIG-LVRT

4.1 Conventional Control System

Two basic sections of DFIG with PV-array CS are GSC and RSC controls. In addition, VSC-CS stays as a basic module. Amid the two CS's important principle of RSC-CS is to eccentrically oversee stator reactive power Q_s as well as stator active power P_s appropriately. Here, i_r signifies the rotor current that moves beside the $d-q$ elements such as i_{gr} as well as i_{dr}, which effectually regulate both P_s as well as Q_s. Using a stator flux, this change is performed. As a result i_{qr} controls P_s, that is a current element of q-axis. MPPT is used to increase the active power reference value P^{ref}.

Moreover, an error amid P^{ref} as well as P_s, is attained by the power controller whereas it generates the controller output, i_{qr}^{ref} indicates the q-axis rotor current reference value. Finally, difference amid actual value i_{qr} and i_{qr}^{ref} produces an error which is presented to the current controller. The current controller output is V_{qr} is assigned to be the q-axis element's reference voltage.

The stator voltage V_s needs to be controlled within limited range, while an unsteady power system is subjected using DFIG that properly tunes reactive- power control of RSC. Conversely, while DFIF is subjected to a steady power system Q_s is adjusted to "0".

At contradictory side error is explained, that is the deviation between the reference voltage V_s^{ref} and actual voltage V_s that is equal to the power controller segment. To the voltage controller, this error is transmitted which produces i_{dr}^{ref} that is assigned as d- axis current's reference signal. Finally, the current controller generates a reference voltage V_{dr}^{ref}, using the error estimated from the difference of i_{dr} and i_{dr}^{ref}.

The dc voltage attainment to a steady level is the benchmark reason for GSC-CS. A reference frame subjected to the stator region is used to convey the particular immediate signals to d-q elements. i_{qgc}^{ref} administrates the reactive power Q_{gc} and i_{dgc}^{ref} administrates the dc voltage V_{dc}. In the developed model, the RNS is proposed in this work, while $Q_{gc}^{ref} = 0$.

4.2 Developed Control System

The developed model makes tighter the divergence of the system from error which controls distributions amid two converters that are for PV array and WT with easily broken ac grid. Since the CS function requires a diminutive time, it is independent to lack and optimum noise explains relating to the machine factors. Therefore, the CS is developed based on the CI. Since the mathematical model of attaining the principles are quite complex by plain fuzzy reasoning, using the GA [9] was executed. The GA-dependent CS has concentrated the error that is based upon the $\hat{V}_s^{ref}$ and $\hat{V}_s$, and the optimized CS has obtained.

The error recognition model explains error function from the integration of no-fault and fault signal in the proposed CS design.

As a result, the CSG attains the responsibility to select if optimization is needed or not. In fact, CSG selects to use the system optimization if fault operation goes ahead of a definite level. In the proposed model, IS-JA optimizes the control gain G which is supplementary raised with the CSG result. The optimization location of G varies based upon error, therefore CS attains the ability to automatically accurate fault signal.

4.3 Objective model

CS is executed by the ISJA-LVRT model [10], the output voltage $V_{dc}^{measured(i)}$ is generated with error used at two different moments $t = 1,2$. As a result, in eq. (11), the error function is calculated from the difference of $V_{dc}^{measured(i)}$ and $V_{dc}^{no\,fault}$, that is further used to the fuzzification. Here, $V_{dc}^{measured}$ signifies the computed voltage at the output as well as $V_{dc}^{no\,fault}$ signifies voltage at the output with no error. The objective model of this paper is to select the least error as shown in Eq. (12) which needs to be minimized using the proposed model.

$$e_i = V_{dc}^{measured(i)} - V_{dc}^{no\,fault} \tag{11}$$

$$e = \max(e_i) \tag{12}$$

5. Proposed IMPROVED SHUFFLED-JAYA ALGORTIHM

The proposed model begins with the initialization phase and all through the estimation rate; the fuzzification result is integrated with the proposed model. Hence, it generates fuzzified minimized function for fitness. Eq. (13) exhibits triangular membership modelled $\mu(x)$ based upon fuzzification in that e signifies fault function of CS, m signifies value z, and x signifies to the upper as well as lower limits correspondingly.

$$+\mu(x)=\begin{cases}0, & e\le x\\ \frac{e-x}{m-x}, & x<e\le m\\ \frac{z-e}{z-m}, & m<e<z\\ 0, & e\ge z\end{cases} \tag{13}$$

The proposed model presumptions the current outperforms the candidate solution that is objective function closer to the whole optimum.

The algorithm steps are stated as follows:

a): Initialization

Similar to other meta-heuristic techniques, the IS-JA method initiates with starting locations for each and every agent produced arbitrarily in a d-dimensional search space as:

$$x_{j,c,0}=x_{min}+r\times(x_{max}-x_{min}); c=1,2,.....,NP \tag{14}$$

x_{max} and x_{min} represents the upper and lower bounds of the j^{th} design variable for c^{th} an agent. r represents an arbitrary count uniformly distributed in the range of [0,1].

b): Dividing into communities

Here, the whole population by means of the size of NP is divided into "m" communities. Hence, in ascending order, the whole population is sorted on the basis of the objective model value of solutions.

Subsequent, to the division population into communities, initialize m candidate solutions (members) of the whole population.

c): Producing a new solution

The worst and optimal solutions are ascertained and the novel solution is subsequently generated using Eq. (1) in each community.

$$x'(j,c,i)=x(j,c,i)+stepsize(j,c,i) \tag{15}$$

d): Evasion from local optima

In local optima, the Meta-heuristics are trapped while they are nearer to the optimum solution. To undertake this problem, 1 dimension of an arbitrarily chosen member in each community following producing its novel location based on c) is arbitrarily chosen and altered using the below formulation

$$x'_{q,r,i}=x'_{q,r,i}+0.1\times rn\times(x_{max}-x_{min}) \tag{16}$$

q and r indicates the chosen variable index for chosen agent respectively. rn indicates normally distributed arbitrary numbers.

e): Applying and evaluating replacement scheme

Here, newly produced solutions are estimated in each community. By the conventional solution, the novel solution will be replaced if the new solution is superior to it. Or else, the conventional solution will be kept unaltered.

f): Combine communities for shuffling

To share information between communities, they are combined. Hence, a single population is created.

This procedure enhances the exploration ability of the IS-Jaya technique and its exploitation.

g): Verifying halting circumstance

If iteration count attains the utmost count of iterations (Max_{it}), the method halts orr else, it returns to (b) for the subsequent round of iteration.

6. Result and Discussion

The developed DFIG-LVRT with PV array for WT was experimented with by exploiting MATLAB, and the outcomes were attained. At first, the conventional LVRT system was designed whereas it shortages the control gain requirement. The developed system model has presented the control increase for modeling the optimized CS. Then the conventional LVRT model, a system with a minimum control gain of one and superior control gain of ten has experimented with the proposed model. Here, the proposed method is compared with the conventional techniques such as LVRT, Minimum constant gain, Maximum constant gain, Genetic Algorithm (GA)-LVRT , Differential Evolution (DE)-LVRT , Particle Swarm Optimization (PSO)-LVRT , Artificial Bee Colony (ABC)-LVRT , Grey Wolf Optimization (GWO)-LVRT and Proposed-LVRT.

Table I summarizes the analysis of the RMSE for the developed LVRT system over the conventional models. RMSE represents the deviation among the actual output as well as measured voltages. The RMSE of the proposed method-dependent CS is superior to the conventional models. Here, the proposed method is 33% better than the LVRT, 23% better than the Minimum constant gain, 73% better than the

Maximum constant gain, 9% better than the GA-LVRT , 25% better than the DE-LVRT , 8.9% better than the PSO-LVRT , 8.8% better than the ABC-LVRT , 8.7% better than the GWO-LVRT .

Table II summarizes the RMSE effect on varying speeds. Here the proposed method performance is analyzed regarding RMSE and shows superior outcomes. Moreover, the Here, the proposed method is 18% better than the LVRT, 46% better than the Minimum constant gain, 16% better than the Maximum constant gain for varying speed 5.

***Table 1** Analysis of RMSE*

Techniques	RMSE
LVRT	66.086
Minimum constant gain	63.368
Maximum constant gain	606.87
GA-LVRT	48.828
DE-LVRT	62.268
PSO-LVRT	48.236
ABC-LVRT	48.861
GWO-LVRT	48.162
Proposed-LVRT	48.173

***Table 2** RMSE effect on varying speed*

Speed (rpm)	LVRT	Minimum constant gain	Maximum constant gain	Proposed model
5	54.741	54.482	577.774	48.781
10	54.782	54.708	577.47	48.772
15	54.847	54.747	572.784	48.764
20	54.746	54.642	567.072	48.704
25	55.085	54.665	567.462	48.726

7. Conclusion

In wind based microgeneration models, three phase induction generators were commonly exploited for single phase operation to cater single phase loads because of several benefits. A new IS-JA algorithm was proposed in this paper for PV array which was operated by exploiting the MPPT method by means of WT in CS. It plays an important role in generating electricity that was a high cost algorithm. Using the proposed model, the analysis on the basis of the optimized CS was carried out. Moreover, this work had differentiated the proposed model with the conventional LVRT system as well as the system with the least and uppermost increase. Moreover, the proposed model was compared with the conventional model was shown in the result analysis. This model showed quantitative analysis such as RMSE computation. The experimental analysis was performed with the conventional models with the efficiency for DFIG-LVRT.

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