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Evolutionary Swarm based Optimization Algorithm for Power Loss Minimization in Distributed Generation System

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Abstract

The electrical energy requirement is increasing day by day as many of the mechanical systems like motor vehicles and industrial engines are compensated with electrical equipment due to its environment friendly nature. However, most of the design of electrical power generation units do not seem to be eco-friendly as that of the electrical motors and drives. Therefore, the concentration has moved towards the non-renewable energy generation possibilities. Power stations that are operated by wind, solar and hydro stations attract the developers due to their minimum maintenance cost and higher operational efficiency. Hence, the combinations of two or three renewable energy sources are clubbed in many places to form a Distributed Generation (DG) setup. Such DG system requires an efficient switching operation for managing the power outcome from different generating stations to meet the load requirement. To meetup such requirement, a combination of Genetic Algorithm (GA) with the Particle Swarm Optimization (PSO) based technique has been developed in this work. A simulated experiment is also conducted in the work to prove the efficiency of the proposed hybrid model over the traditional GA and PSO approaches.

Keywords: Power optimization, grid system control, energy balancing, power loss management, energy storage model

1. Introduction

The renewable energy based distributed generation stations are developed to reduce the carbon emission issue and increase energy efficiency. The DG systems are also referred as on-site generation unit as it is kept near to the distribution society. The transmission loss of

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the DG system is also comparatively less over the conventional generating stations as the distribution society is very close to the generating station. In some cases the DG systems are also connected with a combination of conventional energy source with the renewable energy plant for supplying energy to the consumer. The main motive of the DG system is to manage the power requirement at the peak load condition. Similarly, the DG systems are having the ability to connect and disconnect themselves from the connected grid based on their power requirement [1-3]. Figure 1 explores a simple architectural view of a DG system connected over a centralized power station.

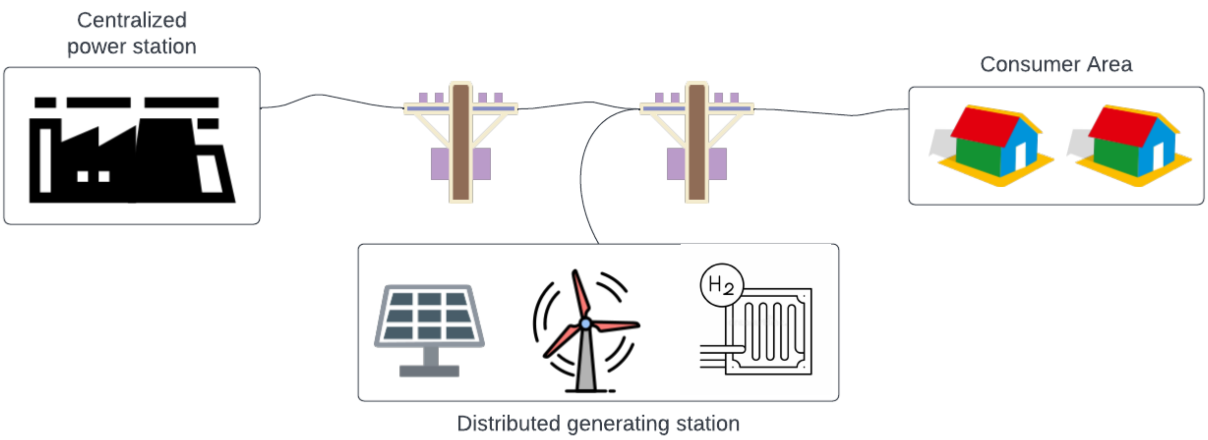

Figure 1. Architecture of a DG based supply system

The benefits of the DG systems are listed below.

- Connecting the inaccessible areas – The DG systems are mostly located in the remote places where the regular transmission lines are not accessible. Places like small island, hilly region and deep forest areas are mostly equipped with the DG units for the power supply.
- Peak load shortage management – As the DG systems are employed with multiple generating units, it can give supply to the consumer on sudden peak demand. The shortage of power supply from a single unit can be compensated with the additional unit connected to it.
- Speed response – The response speed of enabling an additional generation unit is comparatively better in the DG systems over the traditional models. In some special cases some ultra-load capacitors are also connected to the system for fulfilling the immediate power shortage in the system for few seconds at the interchanging period.

- Minimum transmission and distribution loss – The transmission and distribution loss of the DG systems are comparatively less as the production unit kept very closer to the consumer station.
- Better power management and reliability – The power, voltage and frequency management of DG system can be done with a control strategy, and it can be achieved easily by adding a micro control unit on each connected unit.

2. Literature Work

The distributed systems that are connected to the load without a main distribution line are represented as island connected distributed system. An optimal theory-based control strategy was designed to manage the power requirement at island connected DG systems. The simulated work gives an improved in terms of overshoot reduction and settling time. The model was also efficient in controlling the active power on the islanded system [4]. A reference current generated based technique was structured to regulate the power flow in a three-phase inverter system. A single flexible control parameter is utilized in the model for managing the active and reactive power oscillations. An improved adaptive filter-based phase locked loop is also equipped in the work to segregate the positive and negative sequence components [5]. A coordination controller design was made to organize the power management at hybrid DG systems comprises of fuel cell, wind turbine, PV and battery resources. The load demand and the excess power requirement are considered in the work for coordination controller analysis and the excess power are utilized in the work to produce the hydrogen required for the fuel cell [6].

The stability of standalone hybrid power system was regularized using reactive power compensation techniques with static VAR compensator. A linear matrix inequality approach was equipped in the work for controlling the static VAR compensator values at variable wind conditions and load fluctuations [7]. A graph theoretic model for power compensation in a radial distribution system with 69 buses was proposed in the work. The method was effective in minimizing the computational cost over the conventional controllers. An average electrical centrality index was calculated in the work for maintaining the reactive power over the traditional multipoint compensation system [8]. A genetic algorithm-based optimization algorithm was developed to control the load response to the DG system. The performance of the proposed design was verified with a smart micro grid system, and it proves betterment in terms of minimization to the daily operating cost [9].

An energy management control strategy was framed for buck type multi-input distributed generation system. A variable inductances equivalent method was equipped in the work to regulate the load and input power of the system. The performance of the work gives an improvement on high conversion efficiency with low distortion output [10]. The demand response of a DG system was addressed with game theoretic technique on a smart distribution grid system. The simulated analysis shows betterment on total power loss management and total production cost [11]. A control theory based on Lyapunov theory and input-output feedback linearization was designed to maintain the power in a DC/AC hybrid power system. The power error at the control inputs was also rectified by the proposed concept [12].

A second-order cone programming-based branch flow technique was designed to maintain the power flow quality at radial distribution networks. The outcome of the proposed model was experimented with an IEEE 32 bus system and found satisfied than the traditional nonlinear programming methods [13]. A spider monkey optimization technique was incorporated with genetic algorithm for estimating an optimum demand side management protocol in distributed generating station. The voltage security state was maintained in a better way by merging the proposed model with learning vector quantization approach [14]. An adaptive fractional fuzzy sliding mode control was structured to control the power flow of hybrid renewable system consists of PV/FC and super capacitor. The simulated outcome indicates an improvement on load regularization at critical variations [15]. A distributed rule-based power management approach was developed for load balancing and power smoothing application in PV and battery based super capacitor. An active compensation model was utilized in the work to regulate the power fluctuations and a distributed supervisory control method was added to the model for handling the state of charge violations [16].

3. Proposed Model

3.1 Genetic Algorithm (GA)

The GA approaches are developed to solve the problems related to control and non-control parameters of a connected system. This technique was primarily inspired from the biological evaluation and hence it is named as genetic algorithm. The main strategy of the genetic algorithm is to make the available features as parent by creating additional sub-features as children. Therefore, the concentrations of the sub-features are improving the prediction and optimization solutions [17-18]. Figure 2 explores the flow phases of a GA model in general.

Figure 2. Flow of GA model

3.1.1 Initial population

The first step of GA model is to collect the set of features or attributes that are present in the available data for operation. Each feature is segregated into different variables based on several categorization process to form genes. Then the appropriated genes are gathered for making a chromosome as a solution to the considered problem. The newly formulated genes are represented with an English alphabet along with a binary representation for their individual chromosomes.

3.1.2 Fitness function

It regulates the extracted feature information to be clubbed with the additional feature information taken away from the input data. It is formulated by assigning an individual rate for the collected features as fitness score. The calculate fitness score will provide the possibility on the formation of a new feature probability as a child.

3.1.3 Selection

Selection is the process of transferring the useful information extracted from the existing feature to the upcoming generation feature called the children. The fitness score calculated by the fitness function estimates the existing features that are to be incorporated for the new one.

3.1.4 Crossover

The crossover phase will act like a fine-tuning phase and that allows the pair of features to form a new feature as individual feature by sharing the useful data with respect to the given crossover point. The change in crossover point will improve the experimental outcome of the given input.

3.1.5 Mutation

Mutation is a kind of fine tuning that can be applied to the new individuals by changing their data in an interchangeable manner through low random probability. This avoids the overfitting problem on the estimations. The mutation gets stopped at the place where the outcomes are seems to be same as of their previous features. Hence the final mutation step is considered as the solution to the given problem.

3.2 Particle Swarm Optimization (PSO)

The PSO algorithms are computationally fast and give a better result over the other traditional optimization methods. The PSO algorithm is having the feature of adaptability and that allows the model to be merged with other optimization tools for parallel processing. The PSO also has the ability to operate with the gradient features and not as like of other optimization model that requires differential input. There are also few fine-tuning options available in the PSO as hyper-parameters to operate the problem in flexible and powerful manner.

Particles are the set of solutions that are available in a research space and the global minimum is the exact solution of the problem located in an unknown place of the research space. However, each particle has its own fitness values as a function for optimization and those particles move over the research space for locating the exact solution location. The velocity parameter available in the fitness function allows the particles to change the places on an iterative method. The vector value of the velocity information changes the direction of particles in a randomized manner over the plane.

The PSO does not contain an updated generation same as like of GA, but it includes a population-based analysis for verifying the available location. Though, PSO don’t have the mutation step for finalizing the solution. Hence it moves their direction by verifying the personal best fitness solution over the global best fitness solution. The optimization block of the PSO is categorized as exploitation and exploration. The exploitation step allows the particles to move for identifying the best solution and the exploration makes the identified solution to be compared over the other solution available in the research space. The solution is detected in this model by balancing the collected solution among the exploration and exploitation steps [19-20].

3.3 Proposed GA-PSO algorithm

The GA and PSO algorithms are combined in the proposed work for obtaining an optimum solution through evolutionary and swarm intelligence analysis. The GA algorithm is employed in the work as primary solution finder as stated in Figure 3 and the PSO will come only at the place where the suggested solution is not satisfied.

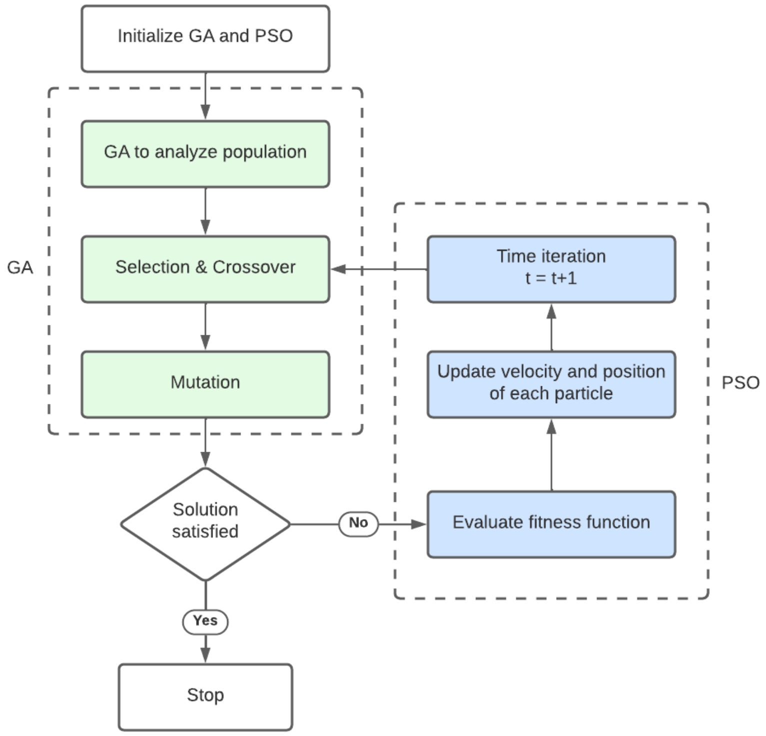

Figure 3. Workflow of the proposed GA-PSO algorithm

In the traditional GA technique, a new generation was created when the created solution was found unsatisfied, but in the proposed approach the new generation is created based on location of the particles available in the free space of the research area. The change in location of the particles of PSO allows the GA to create generation from an optimum location of the available features. This minimizes the amount of generation created in the work for reducing the computational complexity of the proposed work.

4. Experimental Work

The simulation model for verifying the efficiency of the proposed approach is employed with a micro wind turbine and solar PV for power generation through non-renewable energy sources. A demand analyzer is equipped in the work for predicting the power requirement from the consumer side and it will be forwarded to the proposed GA-PSO based algorithm for finding an optimum solution for organizing the operation of the connected systems. A battery storage system is also included in the work to utilize the unused energy produced from the PV and turbine at non-peak load time. Similarly, the battery storage unit also supports the PV and turbine model on peak demand time. A DC/DC bi-directional converter is employed in the work for making the battery to charge and discharge based on the power requirement. Figure 4 indicates an architectural overview of the simulation setup.

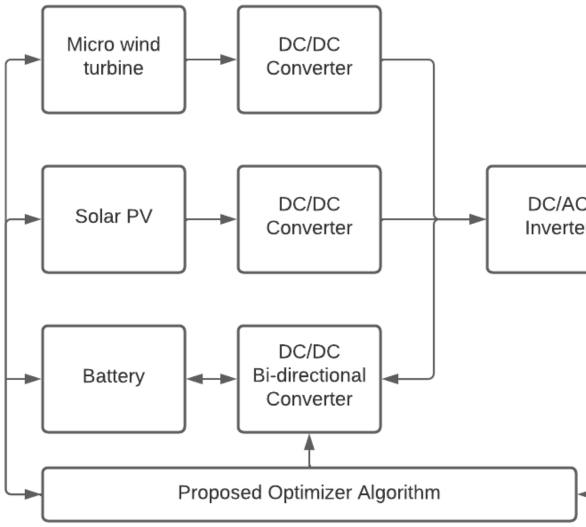

Figure 4. SIMULINK model of the utilized grid system

The performance of the proposed model is analyzed in a SIMULINK tool where the load demand is fixed to 2W irrespective of time. The operational change of the connected systems based on the solution given by the optimizer is shown in figure 5. The response of the battery unit found satisfied in terms of the reaction speed at the time of demand in both PV and wind turbine models. The load interchangeability among the PV and wind turbine is also found satisfied as of the battery power sharing time.

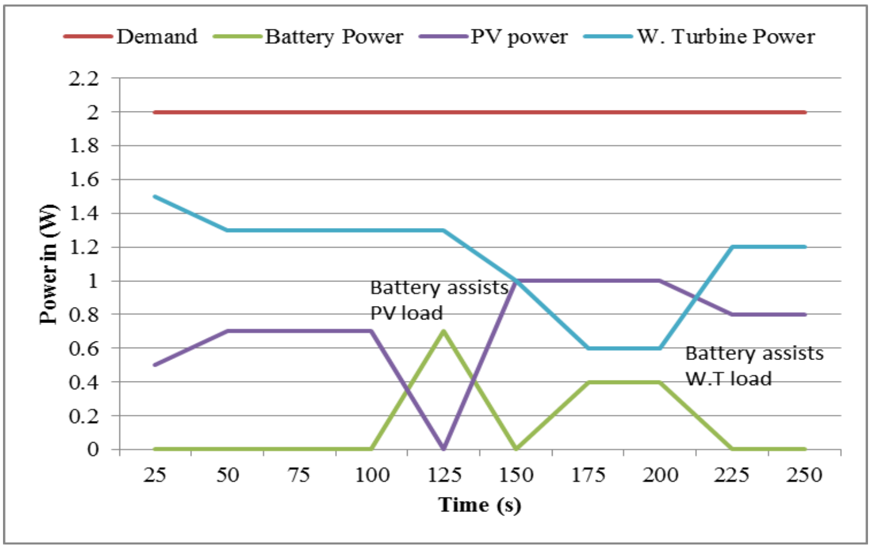

Figure 5. Performance of the proposed GA-PSO based algorithm on power management

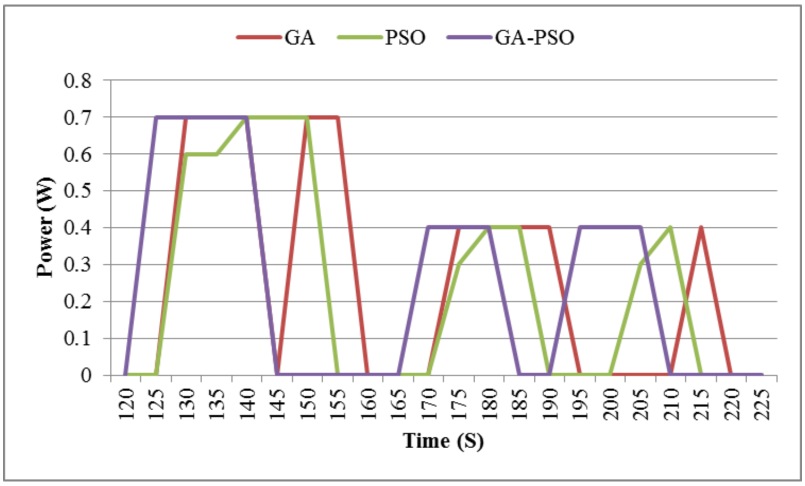

Figure 6. Performance of the proposed GA-PSO model over the traditional approaches on battery power management

Figure 6 indicates the response speed of the proposed system over the traditional methods at the time of peak demand. The response of the regular PSO is found almost similar as of the proposed hybrid model but it lags in certain cases for producing the required output for certain time limit. Similarly, the load cut time from the battery storage unit is also taking a longer response time. The performance of the GA is found satisfied in terms of supplying the power to the demand, but it also lags at in terms of response speed than the proposed hybrid model.

5. Conclusion

The DG system has been developed to share the power load demand on peak time by sharing the power generated from the connected sources. It is achieved by employing a switching circuit for interchanging the power generation process. The proposed work has designed a GA-PSO based hybrid algorithm for operating the switching process in an efficient manner. A simulation model has been structured in the work that consists of wind turbine, solar PV, and battery storage for meeting the load demand. The experimental work is found satisfied in terms of switching speed of operation of the proposed model over the regular GA and PSO models. Similarly, the power management process is also found satisfied by assisting the solar PV and wind turbine at their shortage time.

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