PSO Based Dispatch and Control of Hybrid Power System with PV-Diesel Generator- A Prototype

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Abstract. A micro-grid is a small-scale power grid that can operate independently or in conjunction with the area’s main electrical grid. Micro-grid paves way to power remote locations and effectively integrate various sources of distributed generation, including renewable. In this paper, an economical way of dispatching PV power and power generated by generators in islanded micro-grid is proposed. Here, part of the micro-grid demand is supplied by PV power station. The demand which cannot be supplied by the PV panel, are dispatched between DGs by solving unit commitment and economic dispatch problems. Unit commitment is carried out using priority list method and economic dispatch particle Swarm optimization. A hardware prototype for the proposed micro-grid dispatch methodology has been developed. Here, commitment and de-commitment of the sources and demands is carried out by generating control signals denoting the ON/OFF status to the sources for different intervals.

Keywords: Hybrid Power Generation System; Micro-grid; Photovoltaic Panel; Unit Commitment; Particle Swarm Optimization; Audrino based ON/OFF control.

1. Introduction

Electricity has become an essential commodity nowadays. However, many rural and remote places are not accessible by the power distribution companies yet. There are two ways of providing electricity to rural communities, either by extending the existing grid or by developing an isolated off-grid power generation entity. Many of the developing countries have accepted these off-grid power generation solutions as the cheapest and most sustainable solutions particularly for rural areas. A MICRO GRID is a small set of loads and distributed energy sources which are inter and intra connected within a small area and that entity can be singly controlled with respect to the main grid. Micro-grids usually consist of distributed generation sources such as diesel generators, solar panels and wind turbines [1]. In this context, this paper investigates a dispatch and control mechanism used in a diesel generator and photovoltaic system based micro grid. The schematic diagram of the proposed micro grid is given in figure 1.

Unit commitment (UC) is a process of turning ON and OFF of the units which are available to supply the forecasted load for particular hour, meanwhile capacity requirement should also be considered [2]. After the decision of UC, economic load dispatch (ELD) is carried out performed the units which are committed. ELD is performed to determine the power output of each and every committed units. It is also to calculate the optimal fuel cost for the thermal units while gratifying the constraints associated with them.
2. Literature review

Priority list is one of the methods by which UC is normally performed and that can also be applied for larger power systems. Priority list technique is the simplest method among all methods to understand. And also it is very fast to compute. In this method the ON and OFF state of the units are considered IC value of each unit is considered and incremental cost (IC) of each unit is computed [2][3].

Karamjeet Kaur and Amarjet Kaur have discussed solving of unit commitment using improved priority list method by which the most economic unit will be committed first followed by the other units in the same hierarchy which is better than other existing priority list methods. Their proposed solution includes the minimum up/down time constraints which are usually neglected in the existing methods. Economic dispatch of the committed units is then done using lambda iteration method. The fast calculation of ED and the simplicity of the proposed priority method leads to competent and methodological approach compared to other conventional method [3].

Md. Sajid Alam and Durga Hari Kiran B have performed UC which includes renewable sources by priority list [4] based particle swarm optimization (PL-PSO) [5] as well as using priority list based genetic algorithm optimization (PL-GA) [6] wherein a unit is committed depending on incremental cost and economic load dispatch by particle swarm optimization and comparison of both the methods is done. Here, both GA and PSO converge to similar optimal solutions. However, in case of PSO the computation time is decreased and good convergence will also be observed.
3. Problem Formulation

The objective of a unit commitment problem (UCP) is to get an optimized schedule to commit the available generating units. This gives optimized minimal operation cost (1) to supply the forecasted system load while considering the power balance constraint (2), unit constraints (3), ramp-rate constraints (4), and minimum ON/OFF constraints (5).

Minimize \( OC = \sum_{t=1}^{T} \sum_{i=1}^{n_g} f_i(P_{i,t}) l_{i,t} + SU_i l_{i,t} (1 - l_{i,t-1}) + SD_i l_{i,t} (1 - l_{i,t}) \)

where,

\[ f_i(P_{i,t}) = a_i + b_i P_{i,t} + c_i P_{i,t}^2 + |e_i| \sin \left( f_i(P_{min,i} - P_{i,t}) \right) \]

Subject to:

\[ \sum_{i=1}^{n_g} P_{i,t} = P_{D,t} \]  

\[ P_{min,i} \leq P_{i,t} \leq P_{max,i} \] for \( i = 1,2,\ldots,n_g \)  

\[ P_{min,i,t} = \max\{P_{min,i},P_{i,t-1} - Ud_i\} \]  

\[ P_{max,i,t} = \min\{P_{max,i},P_{i,t-1} + Up_t\} \]  

\[ X_{i,t}^{ON} \geq T_{i,t}^{ON} \rightarrow l_{i,t-1} - l_{i,t} = 1 \]  

\[ X_{i,t}^{OFF} \geq T_{i,t}^{OFF} \rightarrow l_{i,t} - l_{i,t-1} = 1 \]

In this work generating units are considered to be diesel generators, for which the start-up costs and shut down costs are zero.

4. Solution methodology

4.1. Priority list approach for unit commitment:

Priority list method determines the priority rank of each generating units based on their Average Full Load Cost (AFLC).

\[ AFLCI = \frac{A_i \cdot P_{max}^2 + B_i \cdot P_{max} + C_i}{P_{max}} \]

The procedure for obtaining unit commitment status by priority list [4] method is given below:

- Determine the priority list. Here, the unit with the least value of AFLC tops the priority list, followed by the other units in ascending order of AFLC.
- Set \( t = 1 \).
- Set the rank of generator \( k = 1 \) and the maximum amount of power supplied by the combination of generators \( P_{m} = P_{max,k} \).
- If \( P_{supplied} > P_{net} \) demand, then go to step 5. Else, increment \( k \), \( P_{supplied} = P_{supplied} + P_{max,k} \) and go to step 3.
- Solve economic dispatch considering the committed units.
If $T = T$, then stop execution. Otherwise, increment $T$, update the operating limits using equations (5), (6) and (7), and go to step 3.

4.2. Economic dispatch by PSO

PSO is a population-based stochastic optimization technique modeled on swarm intelligence. Here, each particle flies in the search space in certain velocity. The particle’s flight is influenced by cognitive and social information attained during its exploration. The PSO can generate highly excellent solutions taking small time for calculation and stable convergence characteristic than many other stochastic optimization methods. The PSO model consists of a swarm of particles moving in a D-dimensional real-valued space of possible problem solutions. Every particle has a position and a flight velocity. During each time step $k$, the velocity is updated and the particle is made to move to a new position. This new position is calculated as the sum of the previous position and the new velocity. The step procedure in implementing PSO to solve ED is:

- Read system data, demand profile, tolerance in power balance mismatch ($\epsilon$), number of particles ($N$), initial inertia weight ($WI$), final inertia weight ($WF$), social scaling factor ($c_1$), cognitive scaling factor ($c_2$) and maximum steps ($K$).

- Initialize iteration count ($k$) as 1 and velocity ($V$) of each particle as 0.

- Numbers of initial particles are randomly generated. The position of each of the particles is represented in $ng$ dimensional space as a vector, $X_p = [P_1^1, P_2^1, ..., P_p^1, ..., P_N^1]$. Each element of $X_p$ represents the real power generated by corresponding generator. Then, the swarm can be expressed as in equation (7). Here, the particles are generated in a way such generator operating limit constraints are satisfied. The position of the particle ($p$) in dimension ($i$) is calculated as in equation (8).

$$X = \begin{bmatrix} P_1^1 & P_2^1 & \cdots & P_p^1 & \cdots & P_N^1 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ P_1^i & P_2^i & \cdots & P_p^i & \cdots & P_N^i \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ P_1^{ng} & P_2^{ng} & \cdots & P_p^{ng} & \cdots & P_N^{ng} \end{bmatrix}$$

$$P_p^i = u * (P_{\max,i,t} - P_{\min,i,t}) + P_{\min,i,t}$$

- Calculate the fitness of each particle using equation (9).

$$fit(X_p) = \frac{1}{\left(\sum_{i=1}^{ng} f_i(P_{i,t}) + 1\right)}$$

- Update the fitness of the local and the global best particle using the equations (10) and (11), respectively.

$$Pbfit_p^k = \min\{Pbfit_p^{k-1}, fit_p^k\}$$

$$Gbfit = \min\{Pbfit_1^k, ..., Pbfit_p^k, ..., Pbfit_N^k\}$$
• Updating the local best position of particles \((Pb_p^k)\) and global best particle \((Gb)\).

• Update the velocity for each of the particles using equation (12).

\[
V_p^{k+1} = WV_p^k + C_1u_1(Pb_p^k - X_p^k) + C_2u_2(Gb - X_p^k) \tag{12}
\]

• Update position of each particle using equation (13).

\[
X_p^{k+1} = X_p^k + V_p^{k+1} \tag{13}
\]

• If the iteration count \(k = K\) (maximum number of iterations), then increment \(t = t + 1\) and go to step 2. Else, go to step 3.

5. Prototype development

A prototype of Micro-grid is constructed in laboratory environment and is tested with all the requirements in the real time Micro-grid. The Micro-grid considered in our project utilizes the available solar energy for meeting the load demand and the remaining part of the load i.e., the net demand (gross demand-Solar power generated) is met by the group of three Diesel Generating units in which minimization of cost [7] is the main objective to be achieved. In the prototype developed the solar power generating unit is replaced by a PV panel [8] and the three diesel generators are made analogous to three transformers. In real time scenario, the grid is an AC grid so the Micro-grid developed has to be converted to AC grid at the end terminals by using inverter circuits. But in the case of prototype the DC Micro-grid is developed and DC loads are considered. DC load demand and solar power generating output for six intervals is taken and is simulated using Matlab codes for UC chart. The schematic diagram, the circuit diagram and the ratings of the prototype are given in Figure 2 and Table 1, respectively.

Arduino is an open source computer hardware and software. This board has a variety of microprocessors and controllers which contribute to design the boards. The boards are furnished with sets of digital as well as analog input/output (I/O) pins. These pins can be interfaced with different expanding boards and any circuit. The features of the board are that the Universal Serial Bus (USB) can also be interfaced by serial communication.

| S.No | Component                   | Rating                      |
|------|-----------------------------|-----------------------------|
| 1    | Solar Panel                 | 10W, 12V                    |
| 2    | Voltage Regulator           | L7812 IC                    |
| 3    | Boost Converter             | 12V TO 24V                  |
| 4    | DG1(Transformer) –24W       | 230/12-0-12V, 1A            |
| 5    | DG2(Transformer) – 12W      | 230/12-0-12, 500mA          |
| 6    | DG3(Transformer) – 5.4W     | 230/9-0-9, 300mA            |
| 7    | Load ( Resistive)          | 10W, 100 Ω                  |
| 8    | Rectifier & Filter Circuits | 12V, 1A                     |
| 9    | Fuse                        | 0.75A, 0.5A,1A              |
6. Results and discussion

Scheduling and control of an islanded micro-grid comprising of the renewable solar power plant and convention diesel generating units are carried out. A hardware prototype to represent the same and the results are discussed in the following sections. Here, one solar photovoltaic power generation plant along with three diesel generators is considered. The load demand data and solar power insolation data used for the validation are given in Table 2. The capacity of solar PV system is taken as 10 KVA. The cost coefficients of diesel generating units are given in Table 3.

The solar power developed by the solar PV generating unit for the given schedule time is estimated using a model discussed [8]. Here, the Matlab SIMULINK model is developed and the values of solar power generated for each insolation value is obtained. Based on the estimated values of real power generated by the solar power generating unit, the net demand, to be supplied by the diesel power generating units, are calculated.

| Interval No. | Time (IST) (hh:mm) | Gross demand (P_D)(kW) | Solar insolation (W/m²) |
|--------------|---------------------|------------------------|------------------------|
| 1            | 08:00               | 1200                   | 500                    |
| 2            | 10:00               | 1950                   | 1400                   |
| 3            | 12:00               | 2370                   | 2000                   |
| 4            | 14:00               | 1550                   | 1800                   |
| 5            | 16:00               | 1429                   | 1000                   |
| 6            | 18:00               | 970                    | 350                    |
Table 3. Cost coefficients of Units

| Sources | a    | b   | c  | P_{min} | P_{max} | e   | f   |
|---------|------|-----|----|---------|---------|-----|-----|
| Unit 1  | 0.0037 | 2   | 10 | 0       | 200     | 40  | 0.08|
| Unit 2  | 0.0175 | 1.75| 12 | 0       | 180     | 30  | 0.09|
| Unit 3  | 0.0625 | 1   | 9  | 0       | 150     | 30  | 0.1 |
| Unit 4  | 0.00834 | 3.25| 10 | 0       | 300     | 20  | 0.075|

Once the net demand is obtained, the combination of generation units committed at each of the schedule interval is obtained using the priority list method. Values of AFLCs and the priority rank of each unit are given in Table 4. The commitment status of each unit for each schedule interval is given in Table 5.

Table 4. Prioritized units based on AFLC

| Unit | AFLC | Priority rank |
|------|------|---------------|
| 1    | 2.7900 | 1             |
| 2    | 4.9667 | 2             |
| 3    | 5.7853 | 4             |
| 4    | 10.4350 | 3             |

Table 5. Unit Commitment chart

| Interval | Net Demand | Unit 1 | Unit 2 | Unit3 | Unit4 |
|----------|------------|--------|--------|-------|-------|
| 1        | 552        | 1      | 1      | 0     | 1     |
| 2        | 285.6      | 1      | 1      | 0     | 0     |
| 3        | 104        | 1      | 0      | 0     | 0     |
| 4        | -112       | 0      | 0      | 0     | 0     |
| 5        | 594        | 1      | 1      | 0     | 1     |
| 6        | 829.4      | 1      | 1      | 1     | 1     |

Once the commitment schedule is obtained, units economic dispatch for each schedule interval is carried out using PSO. The economic dispatch output obtained using PSO is given in Table 6 and the economic dispatch output obtained using lambda iteration method is given in Table 7.

It has to be noted that the cost obtained using PSO is lesser than the cost obtained using lambda iteration method.

All the components of micro-grid are connected together in parallel i.e., one PV panel of 10W and three units of transformers (5.4W, 12W, 24W) [9] are connected in parallel. In our work six intervals in a day are considered and the load demand for each interval of time and three units of transformers are controlled according to the unit commitment chart developed and is implemented by using Arduino generated signals.
Table 6. ED schedule using particle swarm optimization

| Interval | Net Demand | Unit 1     | Unit 2     | Unit 3 | Unit 4 | Cost(Rs) |
|---------|------------|------------|------------|--------|--------|----------|
| 1       | 552        | 194.7986   | 143.6857   | 0      | 213.5706 | 2258.3  |
| 2       | 285.6      | 196.3796   | 89.1849    | 0      | 0       | 871.71  |
| 3       | 104        | 104.0415   | 0          | 0      | 0       | 289.13  |
| 4       | -112       | 0          | 0          | 0      | 0       | 41      |
| 5       | 594        | 173.1899   | 171.5669   | 0      | 249.3328 | 2642.5  |
| 6       | 829.4      | 200        | 180        | 150    | 300     | 4752.9  |

Total Cost: Rs. 10855.54

Table 7. ED schedule using lambda iteration

| Interval | Net Demand | Unit 1     | Unit 2     | Unit 3 | Unit 4 | Cost(Rs) |
|---------|------------|------------|------------|--------|--------|----------|
| 1       | 552        | 200        | 142.6      | 0      | 209.4  | 2240.7  |
| 2       | 285.6      | 200        | 85.6       | 0      | 0      | 867.02  |
| 3       | 104        | 1240       | 0          | 0      | 0      | 284.22  |
| 4       | -112       | 0          | 0          | 0      | 0      | 41      |
| 5       | 594        | 200        | 156.2      | 0      | 237.8  | 2533.8  |
| 6       | 829.4      | 200        | 180        | 150    | 300    | 4752.9  |

The gross load demand and PV panel output power in each interval along with the net demand (in prototype simulated data is scaled down) is shown in the Table 8.

The unit commitment chart developed for the net demand data in Matlab for six intervals of time is scaled down and is implemented in prototype for all intervals. The Unit commitment chart implemented for controlling the transformers is tabulated in Table 9.

In the considered micro-grid scheduling and controlling of diesel generators has to be done for the demand which is not met by the solar power generating units. Scheduling is done by solving Unit Commitment Problem using priority listing method based on which DG’s are ranked based on the AFLC.

Table 8. Net demand in Prototype

| Interval Number | Gross demand (W) | PV panel output power (W) | Net demand (W) |
|-----------------|------------------|---------------------------|----------------|
| 1               | 10               | 3                         | 7              |
| 2               | 20               | 5                         | 15             |
| 3               | 40               | 6                         | 34             |
| 4               | 30               | 5                         | 25             |
| 5               | 20               | 4                         | 16             |
| 6               | 10               | 2                         | 8              |
Table 9. Unit Commitment Status of the prototype

| Interval number | Net demand (W) | Unit 1 (24W) | Unit 2 (12W) | Unit 3 (5.4W) |
|-----------------|----------------|--------------|--------------|---------------|
| 1               | 7              | 0            | 0            | 1             |
| 2               | 15             | 0            | 1            | 1             |
| 3               | 34             | 1            | 1            | 1             |
| 4               | 25             | 1            | 0            | 0             |
| 5               | 16             | 0            | 1            | 1             |
| 6               | 8              | 0            | 0            | 1             |

Economic Dispatch problem is solved using two different methods namely Lambda iteration method and Particle Swarm optimization method [5] [10]. Both UCP and Economic dispatch problem are solved in Matlab platform and the scheduling results are discussed in the above sections. Controlling of micro-grid includes the controlling of three available DG’s (transformers in prototype) according to the Unit commitment chart developed in the Matlab and Unit commitment is implemented in the prototype by using control signals which are generated by the Arduino. Thus scheduling of DG’s is carried out in Matlab and control of the micro-grid is carried out in the prototype developed.

7. Conclusion
It can be observed from the results that PSO [5] [10] method provides a better converged solution without any initial conditions as compared to lambda iterative method. The optimized cost in PSO is slightly greater than lambda iterative method since it takes into consideration the valve point coefficients for better convergence. It is shown that unit commitment schedule can be translated into control signal by turning ON/OFF different LEDs analogous to generating units. Therefore, it is seen that Arduino boards are viable to control a generator as per the UCP schedule.

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