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Dynamic Programming Method with GA for Optimal Power Flow in Micro-grid

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Abstract:
The Micro-grids are the recent power solutions, as the need of power increases day by day. The micro-grid has many renewable energy resources built in. The renewable resources are not constant power sources. As the physical parameter varies the power generation also varied. To deliver the power from generation to load balanced, energy storage devices plays main role in it. The energy storage can be a battery or flywheel, for balanced power supply. The optimal power flow with the thermal systems or hydro-thermal combined systems solved usually with linear programming approach or gradient search procedure. But for the case of Microgrid, the power generation and consumption is based on the energy storage as it is used as the energy balancer. The energy storage elements changes the energy with respect to time. This makes the problem complex to solve using gradient search or linear programming. In this project the optimal power flow problem is solved with dynamic programming method and genetic algorithm (GA). with the inclusion of energy storage constraint, voltage limit, current limit and power limit. It optimizes the power flow at the point of common coupling between microgrid and the utility grid.

Keywords: *genetic algorithm, dynamic programming, optimal power flow, micro-grid*

1. Introduction

The optimal power flow solved by many methods like linear programing, sequential programing and with many evolutionary algorithms. The optimal power flow problem is required in the Microgrids where many batteries and various types of power genration is available. As many batteries are connected in the microgrids there is a need of monitoring and control of the battery power to provide the fully charged battery to peak load demand in the microgrid system or empty batteries to charge mode. To implement this concept optimal power flow technique is required. The battery power varies according to the change in time. So the time dependent equation are mandatory. So the power flow equation considering time domain fails to converge (Levron, 2013). The dynamic programing method with genetic algorithm makes this happen. So the power flow equations are made as time dependent equations and made to solve the problem.

2. Literature survey

The previous articles that discuss the basics of the problem are discussed in this chapter. The main concepts related to configuration control and energy managements are discussed by vesquez J.C in 2010. The AC-DC converter and DC-AC converters are very much useful for the Photovoltaic system (PV), fuel cell system and micro turbine for conversion. The DC-AC converters are not sufficient to handle the problem of transients. Droop control techniques are essential in controlling the inverters, to make it better to handle transients.

The droop control can operate microgrid as both grid connected and islanded mode smoothly, flexible and grid interactive microgrid. But the battery charging, discharging state of charge is not considered as it becomes more controllable [1-5]. In 2008 Burkland. E discussed the Energy Management (EMS) system. Tsikalakis in 2008 focuses on the functionalities of the Microgrid Central Controller, which is responsible for the optimization of the Microgrids operation. Majumder (in 2010) deals with the real and reactive power flow between utility and microgrid using back-to-back converters. Nikkhajoei (2007) describes the power flow analysis approach for a microgrid with accurate and efficient representation of electronically coupled distribution generator. The dq0 frame based solution in a microgrid and with power electronics interface and with distributed generation unit on a closed form solution are presented. Vieira(2004) presented a novel modeling approach based on the individual phase representation, which allows the three-phase power-flow problem to be solved in a phase-decoupled way i.e., each phase can be solved separately without the utilization of symmetrical component co-ordinates. (Padhy, 2004) gives a survey on unit commitment problem with mathematical formulations, and general backgrounds of research and developments for past 35 years based on more than 150 published articles. The collected literature has been divided into many sections on Unit Commitment problem under both the regulated and deregulated power industry. Celli (2005) has formulated the problem in multi objective. The function involves, Cost of network upgrading, Cost of purchased energy, Cost of energy losses and Cost of energy not supplied. . In a previous research, paper (Levron, 2012) derived the optimal energy management of a secondary storage device that optimizes the efficiency of a power source. In practical power system the rating of the generator and reducing its stress is considered. These would be attained by minimization of the peak power demanded from the generator. Thus, in the paper (Levron, 2012) shows generic approach for optimal "peak shaving" strategy. The paper (Levron, 2010) work suggests an analytic design method for the optimal energy storage of fueled systems, with the constraint of storage capacity. This article (Brekken, 2001) is focused on an analysis of the feasibility of using large-scale energy storage to improve the predictability of a wind farm output. This paper discusses about the safer and cost effective operation of the micro-grid with energy storage devices. The solution of optimal power flow with effective utilization of batteries and the generator are studies with optimal allocation of power to the batteries and generators.

2. Objective of Present Paper

- Formulation of optimal power flow including energy storage constraint.
- Application of dynamic programming method for solution of the above problem.
- Reducing the power consumption from utility grid.
- minimizing the total operating cost of micro-grid interfaced power system.
- Minimizing the network losses.
- Application to a real time system.

3. Methodology

- Time based equations for dynamic programming equation
- Genetic algorithm based solution method
- Constraint inclusion
- Building IEEE-14 bus system as micro-grid system.
- Testing the entire programming with it.

4. Problem definition

Storage devices are modeled by an inner state variable – the stored energy E(t). They are defined by a general State equation, f(.) given by (levron, 2013)

Storage devices:

$$\Delta E_i = f_i(P_i, E_i) \qquad (1)$$

The objective is to minimize the overall cost of energy import from the public grid, determined by incoming power at the PCC. For a single phase system the objective is

$$minimize \int_0^T P_1(t).C(t)\,dt \qquad (2)$$

where,

C(t) - is a price signal ($/MW), usually a time-dependent function

i – bus index or bus numbers

N – Number of buses Each bus is described by four independent signals

Pi (t)– the active power, injected from the bus into the grid (positive for generators, negative for loads)

Qi (t)– the reactive power, injected into the grid.

Vi (t) – the voltage magnitude of the bus.

δi (t) – the phase angle of the voltage Vi

the cost function (2) has the equation as continuous for this can be rewritten as discrete with cost curve. The cost curve taken is concave. So the quation of the concave curve is shown below.

$$\textbf{minimize}\, F_i\left(P_i(t)\right) = a_i P_i^2(t) + b_i P_i(t) \qquad (3)$$

Constraints used are given as follows (levron, 2013)

- Power line

$I_{ij}(t) < I_{ij}max$ (4)

- Load

Pi(t) = -PL,i(t) (fixed) (5)

Qi(t) = -QL,i(t) (Fixed) (6)

Vi,min ≤ Vi(t) ≤ Vi,max (7)

Free variables: $Vi(t), \delta i(t)$

- Renewable generator

$Pg(t) = +Pg,i(t)$ (fixed) (8)

$Qg(t) = +Qg,i(t)$ (Fixed) (9)

$Vi,min \leq Vi(t) \leq Vi,max$ (10)

Free variables: $Vi(t), \delta i(t)$

- Storage devices

$Ei(t)$ = Stored Energy or State Of Charge (SOC)

- Typical constraint:

$Vi(t) = Vs,i$ (fixed) (11)

$0 \leq Ei(t) \leq Eimax$ (12)

$Pi,rated \leq Pi(t) \leq +Pi,rated$ (13)

State equation (one-phase):

$$\frac{d}{dt}E_i = f_i(P_i, E_i) \quad (14)$$

- Free variables:

$Pi(t), Qi(t), \delta i(t), Ei(t)$

- The Point Of Common Coupling (PCC)

The PCC is always indexed as “1” i.e slack bus

$\delta 1,(t) = 0$

$V1,(t) = Vin$, (fixed) (15)

$Q1,min \leq Q1(t) \leq Q1,max$ (16)

$P1,min \leq P1(t) \leq Q1,max$ (17)

Variables: $P1(t), Q1(t)$

5. Genetic algorithm

The genetic algorithm is evalutionary algorithm which is used to solve many complex problem. Here genetic algorithm is used to solve the complex time dependent equation to identify the energy stored in the renewable energy resources. As general genetic algorithm the random population is made with the power generation limit of each generation bus and energy storage devices. Then evaluvation of fitness with respect to each time is considered. The optimal value of storage energy and renewable generation is optimized by minimizing the cost funtion. The procedure is given below.

- Step (i): Intialize the population as the generation value for 4th and 5th generator, battery energy with 2nd and 3rd generation bus for first hour and iteration count.
- Step (ii): Calcualte the fitness value and solve newton raphson power flow for power balance and voltage limit cheking
- Step (iii): Do the crossover, mutation and selection.
- Step (iv): Go to step (ii) do it till the end of iteration count.
- Step (v): Now increment the hour and start from step (i).
- Step (v): display the graphs and results.

6. Test system

Here to check the problem solution a modified IEEE 14-bus system is used with 24-hour load data. It is used with two energy storage bank and two hybrid energy generator system. The below figure depicts the test system used. The below figure shows the 2nd bus and 3rd buses carries the battery energy storage devices. All the other load data, line data generator data are choosen same. And 24-hour data is assumed to increase from 20% to 100% and falls sudden to 20% and increase again for studying the dynamical condition of battery energy storage devices. The load curve is given in fig.2.

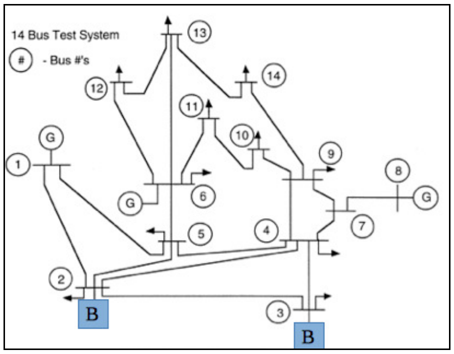


Figure 1: Modified IEEE 14 bus data

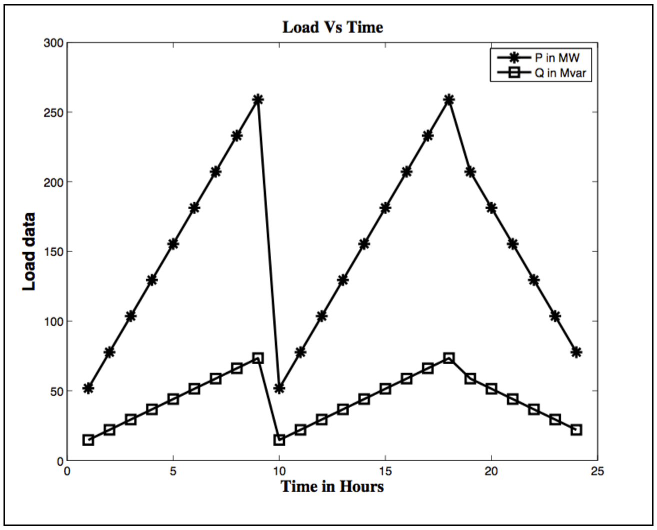


Figure 2: Load data as daily load curve

7. Results and Discussion

The optimal power flow is formulated as dynamic equation and it is solved using the genetic algorithm. The results are graphed and tabulated below. Table 1 shows the each hour load data, cost converged from genetic algorithm and total cost operation cost of the system is identified with losses. The total generation equal to load plus losses are satisfied for each hour. And for lower loading conditions the cost vaue and total operating costs are less and for higher loading conditions losses and cost are high.

Hour	Load in MW	Optimal Cost value in $	Total loss in MW
1	51.80	146.19	0.29
2	77.70	198.86	0.39
3	103.60	255.34	0.76
4	129.50	313.37	1.40
5	155.40	384.89	2.31
6	181.30	459.82	3.37
7	207.20	540.23	5.11
8	233.10	625.37	6.66
9	259.00	716.03	8.52
10	51.80	147.47	0.26
11	77.70	194.81	0.42
12	103.60	248.87	0.89
13	129.50	312.73	1.50
14	155.40	383.80	2.28
15	181.30	458.99	3.37
16	207.20	540.48	4.98
17	233.10	625.57	6.56
18	259.00	715.79	8.10
19	207.20	540.47	4.77
20	181.30	458.26	3.51
21	155.40	387.04	2.13
22	129.50	313.78	1.34
23	103.60	255.57	0.89
24	77.70	190.09	0.47

Table 1: Load, cost and total loss for daily load curve

The fig.3 shows the graph ploted between the cost in $, Power generated in each line and total losses in each hour. The graph shows that the increase in cost and losses are more for higher loading conditions.

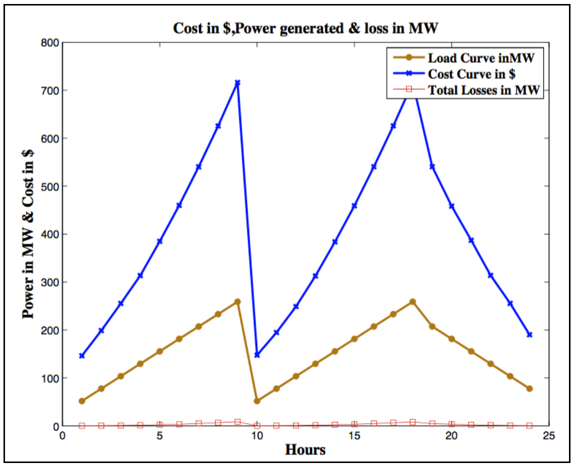


Figure 3: Cost graph in $ with load data and losses

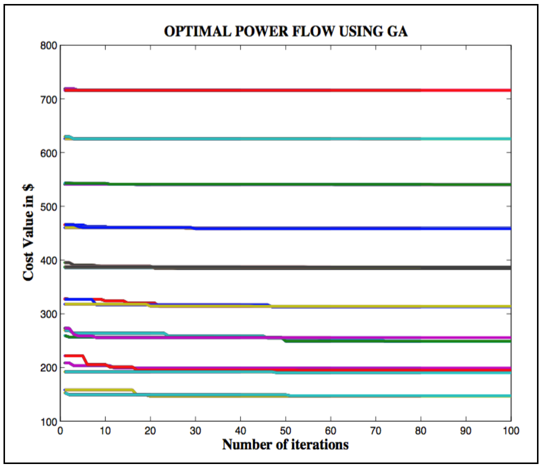
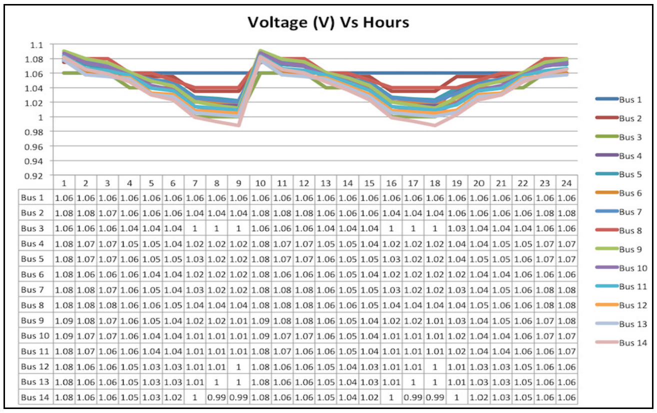


Figure 4: Convergence graph in each hour

The optimal allocation of power is done by the genetic algorithm each hour. The fig.4 shows the optimal allocation of power in each generator including energy storage devices. The energy storage devices also considered as power generator in this paper. The optimal value of the cost is identified in each iteration by satisfying the constraints.The voltage constraint is satisfied which is shown in the fig.5. All the voltage are with in limit and it is visible that the slack bus (grid) has the constant voltage values in all the iterations.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Bus 1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Bus 2	1.08	1.08	1.07	1.06	1.06	1.06	1.04	1.04	1.04	1.08	1.08	1.08	1.06	1.06	1.06	1.04	1.04	1.04	1.06	1.06	1.06	1.06	1.08	1.08
Bus 3	1.06	1.06	1.06	1.04	1.04	1.04	1	1	1	1.06	1.06	1.06	1.04	1.04	1.04	1	1	1	1.03	1.04	1.04	1.04	1.06	1.06
Bus 4	1.08	1.07	1.07	1.05	1.05	1.04	1.02	1.02	1.02	1.08	1.07	1.07	1.05	1.05	1.04	1.02	1.02	1.02	1.04	1.04	1.05	1.05	1.07	1.07
Bus 5	1.08	1.07	1.07	1.06	1.05	1.05	1.03	1.02	1.02	1.08	1.07	1.07	1.06	1.05	1.05	1.03	1.02	1.02	1.04	1.05	1.05	1.06	1.07	1.07
Bus 6	1.08	1.06	1.06	1.06	1.04	1.04	1.02	1.02	1.02	1.08	1.06	1.06	1.06	1.05	1.04	1.02	1.02	1.02	1.02	1.04	1.04	1.06	1.06	1.06
Bus 7	1.08	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.02	1.08	1.08	1.08	1.06	1.05	1.05	1.03	1.02	1.02	1.03	1.04	1.05	1.06	1.08	1.08
Bus 8	1.08	1.08	1.08	1.06	1.06	1.05	1.04	1.04	1.04	1.08	1.08	1.08	1.06	1.06	1.05	1.04	1.04	1.04	1.04	1.05	1.06	1.06	1.08	1.08
Bus 9	1.09	1.08	1.07	1.06	1.05	1.04	1.02	1.02	1.01	1.09	1.08	1.08	1.06	1.05	1.04	1.02	1.02	1.01	1.03	1.04	1.05	1.06	1.07	1.08
Bus 10	1.09	1.07	1.07	1.06	1.04	1.04	1.01	1.01	1.01	1.09	1.07	1.07	1.06	1.05	1.04	1.01	1.01	1.01	1.02	1.04	1.04	1.06	1.07	1.07
Bus 11	1.08	1.07	1.06	1.06	1.04	1.04	1.01	1.01	1.01	1.08	1.07	1.06	1.06	1.05	1.04	1.01	1.01	1.01	1.02	1.04	1.04	1.06	1.06	1.07
Bus 12	1.08	1.06	1.06	1.05	1.03	1.03	1.01	1.01	1	1.08	1.06	1.06	1.05	1.04	1.03	1.01	1.01	1	1.01	1.03	1.03	1.05	1.06	1.06
Bus 13	1.08	1.06	1.06	1.05	1.03	1.03	1.01	1	1	1.08	1.06	1.06	1.05	1.04	1.03	1.01	1	1	1.01	1.03	1.03	1.05	1.06	1.06
Bus 14	1.08	1.06	1.06	1.05	1.03	1.02	1	0.99	0.99	1.08	1.06	1.06	1.05	1.04	1.02	1	0.99	0.99	1	1.02	1.03	1.05	1.06	1.06

Figure 5: Voltages in each bus after convergence for 24-hours

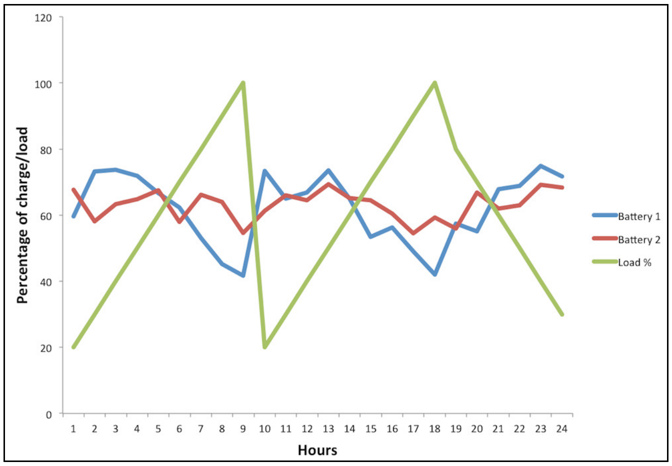


Figure 6: Battery dynamics curve with daily load data

Fig.6 shows the battery dynamics curve in daily load curve. The daily load curve is take in percentage and the energy stored in the battery is also taken as the percentage and battery constraint is satisfied and the charging and discharging of battry is within limit. And it can be seen that the battery energy storage is within the 40% to 80% due to proper allocation of power generation by genetic algorithm. So the battery life span may increase. When the load is increasing the battery discharges. When the load is dipping battery charges, so the dynamics of battery in a micro-grid is achieved. All the other constraints are satisfied and result are displayed.

8. Conclusion

The optimal power flow in a micro-grid is solved with the dynamic programing based genetic algorithm. The problem formulation is made with the time based equation and voltage, current, power balance, generator limits are also considered in time based equation as the battery dynamics has to be studied. Here the objective function is cost function and it is solved for minimization. The optimal allocation of the power is made using the genetic algorithm. The algorithm is tested with the new modified IEEE 14-bus system to validate the results with the 24-hour data.

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