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Research Article

Demand Side Management Based on Model Predictive Control in Microgrid in Grid Connected Mode

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Abstract

In this article, the control method of the economic predictive model for the use of the efficiency tariff of the photovoltaic backup system, diesel generator and microgrid, connected to the grid using the closed loop control system, the optimal open loop control, and also through the control and strengthening of the primary open loop has been The main goal of this study is to minimize the power grid energy and fuel costs by evaluating the limits related to the level of fuel level in diesel fuel tanks. In addition to complying with the restrictions among the controllable variables, this control method also meets the load requirements. In order to obtain the benefits of feedback and predict the optimal power timing as a back-up energy system control problem, as well as the diesel generator connected to the microgrid, it is modeled based on the linear programming structure. Specifically, the analysis is divided into two groups. The first case in the alternative model is when: an outage occurs between 7 AM and 6 PM and the other in the grid energy state occurs when the grid is available for more than 24 hours. Energy performance shows, cost savings and income, in the control of the daily economic forecasting model has improved. As long as, daily energy saving is up to 52%, while diesel energy is up to 85%. Optimum operation control can be well associated with uncertainty and disturbance in the result.

Keywords: Demand side management, Microgrid, Renewable energy resources, Model predictive control.

Highlights

- Using a photovoltaic backup system and a diesel generator connected to the microgrid.
- Assessment of limits to fuel level in diesel tanks.
- Predictive model control algorithm to determine optimal values of future control inputs in a closed loop system.
- Gray Wolf Optimization Algorithm by Investigating Smart Grid Complexity with Uncertainties Related to PHEV Charging Behavior.

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1. Introduction

The use of smart grids and the utilization of renewable energy sources alongside the existing grids can be highly effective in increasing grid utilization and improving the efficiency of power networks [1]. If we want to increase the reliability of power systems, various solutions have been analyzed and discussed in the literature. One of these methods is load management on the consumer side, and another proposed approach is the use of microgrids [2]. Microgrids have been used in both islanded and grid-connected modes. It is worth noting that despite advancements in energy storage unit technology, the use of this technology is not yet sufficient to meet the needs of the power industry on a large scale [3]. The main reasons are the high initial cost and maintenance expenses. Therefore, it is not recommended on a large scale, and other methods need to be employed [4]. One of the cost-effective methods for providing continuous power is the combination of grid-connected photovoltaic systems with battery-less diesel generators [5].

One of the important aspects of the proper utilization of hybrid systems is the use of control methods, which are crucial for voltage stability and frequency control [6]. Numerous articles on this topic have been published in journals, and these control methods have been presented at the primary, secondary, and tertiary levels. The primary control focuses more on frequency and voltage stability, the secondary control reduces frequency and voltage deviations, and the tertiary control addresses performance and scheduling challenges [7].

One of the critical control methods for microgrids is the development of a management strategy to reduce losses and operational costs. Various control methods have been employed in the literature to achieve the objectives of power grids [8]. One of the most important control methods is the use of model predictive control (MPC). MPC is an optimal control method that uses a mathematical model of the system to predict the system's future behavior and determines the optimal control actions by solving an optimization problem with control constraints. In MPC, the control signal model is always obtained by solving an optimization problem [9]. The cost function of the optimization problem can be the consumed energy, fuel consumption, tracking error energy, and so on, depending on the type of plant. When designing the parameters of a PI controller, we only consider the frequency or time-domain characteristics (such as overshoot, settling time, bandwidth, etc.) and do not consider the energy consumption of the control system [10]. However, the main advantage of MPC is the online optimization along with considering the physical constraints of the system. The main advantages of MPC can be summarized as follows: 1) Ability to consider energy and cost storage (by including the energy of the control signal in the cost function, the energy consumption of the system can be reduced, which in turn will reduce the system costs); 2) Ability to control multi-variable systems (the extension of MPC to multi-variable systems is straightforward and does not introduce significant complexity, while the design of classical controllers like PID for multi-variable systems is much more challenging); 3) Effective disturbance rejection; 4) Easy implementation in digital systems (unlike the complex optimal control theories that require solving nonlinear differential equations, MPC can be easily implemented on digital computers); and 5) Industrial applicability (MPC has originated from industry, and many of these control strategies have proven their effectiveness on industrial plants).

The main drawback of MPC is the need for an accurate process model, as in this controller, the future behavior of the system must be predicted in the first step. Therefore, if the mathematical model of the system is not accurate, the system output predictions will not be valid, leading to errors [11].

2. Innovation and contributions

In this paper one of the distinguishing features of this study is the simultaneous minimization of the energy costs of the grid and the fuel costs of the diesel generators, considering the relationship between the controllable parameters and the fuel level in the diesel generator tank in demand-side management. The main objective of this paper is to minimize the electricity grid energy and fuel costs by evaluating the constraints related to the fuel level in diesel fuel tanks. Optimal operation control can effectively deal with the uncertainty and disturbances resulting from the use of the proposed control methods. This paper examines a real-case study to prove the efficiency of the proposed economic model predictive control method for a photovoltaic-diesel generator microgrid system. The overall savings in grid and diesel generator costs, considering the integration of the photovoltaic system and the daily profit and revenue compared to the main costs, are presented. Reducing the grid energy costs and fuel consumption costs leads to improved energy performance and revenue generation through the sale of excess photovoltaic energy to the main grid. Photovoltaic electricity is prioritized during peak price periods to meet the load demand.The economic model predictive control considers the constraints related to the fuel levels in the diesel fuel tanks and demonstrates robustness in the face of uncertainty and disturbances, which are addressed before the next control period, and the receding horizon can be used to correct the control variables. Given that one of the drawbacks of the model predictive control method is that if the mathematical model of the system is not accurate, the system output predictions will not be valid and will result in errors, in this paper, the Grey Wolf Optimization Algorithm (GWOA) is used to improve the performance.

Among the innovations applied in this study, the following can be stated:

The use of the Grey Wolf Optimization Algorithm (GWOA) is considered due to the complexity of the grid with uncertainties related to the behavior such as Plug-in Hybrid Electric Vehicle (PHEV) charging, grid demand, and energy prices. Here, the proposed Distributed Feeder Reconfiguration (DFR) reports a wide range of non-linear, stochastic, and non-convex integer programming problems that require specialized optimization methods to find the global optimal solution. Subsequently, the GWOA was used to solve the defined stochastic DFR. The Grey Wolf Optimization (GWO) algorithm, which mimics the social behaviors of grey wolves, was proposed by Mirjalili et al. in 2014 [15]. Wolves live in packs of 5 to 12 members, and the pack has a well-defined hierarchy. This method can be used as an innovation in the present paper.

3. Materials and Methods

In this paper, the economic model predictive control method is used to control and optimize the operation of photovoltaic systems, diesel generators, and microgrids in both islanded and grid-connected modes. To achieve optimal performance, control methods including closed-loop control systems, open-loop optimal control, and initial open-loop reinforcement control have been used [13].

4. Results and Discussion

This paper examines two scenarios based on the economic model predictive control method for the photovoltaic-diesel generator microgrid system. The first case considers a power outage from 7:00 AM to 6:00 PM, during which most university activities take place. The second case considers the availability of grid power in a 24-hour period in a grid-connected mode [14].

4.1. Evaluation of the predictive model in the case of grid power outage

An economic predictive model is proposed to operate the microgrid in alternative conditions, considering the worst-case scenario of a grid power outage from 7 AM to 6 PM. The analysis is possible through the design of the economic model predictive control without considering the effects of the photovoltaic power plant. The performance of the economic model predictive control is evaluated by considering the optimal sizing of the photovoltaic power plants [12]. The main grid and the diesel generator are the baseline cases. The diesel generator acts as a backup energy source. Based on the review and the results obtained, the grid energy and the diesel generator performance have been significantly reduced compared to the baseline. The overall savings in grid and diesel generator costs, considering the integration of the photovoltaic system and the daily profit and revenue compared to the main costs, are presented. The total cost savings can be calculated by comparing the cost of the grid power system and the cost of the diesel generator system, considering the photovoltaic system with the main grid for the grid-connected case without the photovoltaic system. Therefore, the economic model predictive control considering the photovoltaic system is more cost-effective. With the non-delivery of diesel generator energy, the photovoltaic power plants will perform better in relation to the economic model predictive control strategies compared to the diesel generators used in the main grid.

4.2. Evaluation of the predictive model in the case of grid power availability

The model predictive control method in this scenario is used in a 24-hour period with grid availability using the grid-connected mode. In the grid-connected mode, the baseline requires a situation where the grid is the only power source for the loads, which is due to the high levelized cost of energy associated with conventional diesel generators.

5. Conclusion

This paper presents an optimal closed-loop control performance considering the economic model predictive control of the coupled energy microgrid. The microgrid has a photovoltaic-diesel generator backup system based on the constraints between the controllable parameters in the time-of-use tariff. The focus areas are: 1) Reduction of grid energy costs, 2) Reduction of fuel consumption costs by evaluating the constraints related to the fuel level in the diesel fuel tanks, which can achieve very good efficiency using the simulations performed in the economic model predictive control method with the main electrical relationship and all diesel generator costs. Finally, the aspect that can be mentioned in this paper is the analysis of the considerable reduction in the operating costs of grid-connected photovoltaic-diesel generator systems by applying an appropriate weight factor range.

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Appendix

Table 1. Diverse variables of simulation.

Variables	Describe	Values
$\rho(t)$	Energy cost	0.06 $\$/kWh$
F_c	Fuel cost	0.973 $\$/L$
F_d	Feed in tariff	0.12 $\$/kWh$
N_{dg}	Number of DG	1
	Rated power of DG	250 kVA
P_{ndg}	Nominal DG's active power	200 kW
$cost\phi$	DG's power factor	0.8
n_{dg}	DG's efficiency	35%
DG parameter	a	0.246
	b_d	0.08145
DG tank's length	L	1.48m
DG tank's width	l	1.02m
DG tank's height	h_{max}	0.23m
Initial fuel amount in the DG tank	h_o	0.225 m
Minimum fuel amount in the DG tank	h_{min}	0.005 m
Sampling time	t_s	1 h
Time horizon	N	24

Table 2. Baseline and optimum control in alternative manner sans PV plant grid.

Variables	Baseline grid+DG	Baseline cost	Grid energy	DG energy
Amounts	1090.5 kWh	368.4 $	446.4 kWh	644.1 kWh

Table 3. MPC in alternative manner sans PV plant grid.

Weighting ratio ω	0-0.618	0.619-1
Grid energy kWh	446.36	380.96
DG kWh	644.1	709.53

Table 4. Baseline and Optimum control in alternative manner investigating the PV plant grid.

Variables	Values
Baseline grid utility+DG	1090.5 kWh
DG energy	98.2 kWh
Grid utility energy	424.1 kWh
Diesel energy not delivered	546 kWh
Diesel energy saving	84.8%
Energy sold	142.4 kWh
Diurnal income	17 $
Entire cost of DG+grid utility	40 $
Entire saving cost	66.6 %

Table 5. MPC in alternative manner sans PV plant grid.

Weighting ratio ω	0-0.618	0.619-1
Grid energy kWh	424.1	159.9
DG kWh	98.2	326.4

Table 6. Baseline and Optimum control in ICM.

Variables	Values
Baseline	1090.50 kWh
Grid utility energy	522.30 kWh
Energy saving	568.20 kWh
Energy sold	142.40 kWh
Baseline cost	117.20 $
Grid energy cost	49.0 $
Diurnal income	17.0 $
Energy saving	58.20 %
Cost saving	58.20 %

Table 7. MPC in alternative manner sans PV plant system.

Weighting ratio ω	0-0.618	0.619-1
Grid energy kWh	522.3	0
DG kWh	294.1	228.2

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