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Effective Energy Management System in Microgrid Employing Model Predictive Controller

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ABSTRACT- The primary focus of this study is to develop an energy management system that regulates the energy transfers between the hybrid microgrid system and the loads connected to it, and the grid via MATLAB/Simulink so as to model the flow of energy. The secondary aim is to make recommendations aimed at the charging and discharging of what is referred to as the hybrid energy storage system (HESS). The results indicate that the proposed algorithm successfully carried out the required task of bridging the HESS charging to discharging ratio in relation to the different operating conditions as well as power management between the microgrid and the network. In this application, a stronger charging power might be employed on the HESS. It has been seen that the HESS is more likely to complete charging within a short time than the greater charging power. A more advanced and efficient energy management system is critical to the microgrid system so that the generation can keep pace with the requirements of the load profile. It is important to take account of load forecasting with regard to power planning and executing so as to know the most suitable action that should be taken. To achieve a general reduction in the cost of operation, in this paper, we propose the use of an advanced Energy Management System (EMS), Model Predictive Control (MPC), to effectively manage the allocation of power in the microgrid.

Keywords: Energy Management System (EMS), Hybrid Energy Storage System (HESS), forecast uncertainties, Model Predictive Control (MPC), microgrids, optimization.

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1. INTRODUCTION

A microgrid can feature both independently and in tandem with the grid, and it offers general controllability. Consequently, inside the islanded mode, the electricity resources' output power has to correspond with the needs of the local loads. Three forms of microgrids can be prominent: There are three types of microgrids: hybrid AC/DC DC, and AC. DC/AC inverters connect renewable energy sources (RES) that produce DC, such as solar photovoltaic to AC microgrids. The DC microgrid shares similarities with its AC counterpart in that they both utilize a DC bus [1]. The main reasons the use of MPC will be compared with traditional controllers such as PID and PI in energy management systems, and on the other hand, microgrid applications are the resource limitations of a computational. The MPC involves the solution of a constrained optimization problem at each control step. This potentially can be very computationally intensive [2-3]. The frequency of computation increases as the control sample time decreases. In this way, the effort in terms of computation required to solve the optimization problem in real time increases. Explicit MPC requires much memory resources since in it one needs to pre-compute controls for most states and then memorize them in the lookup table, which is inconvenient for medium to large-scale problems. MPC success relies on how precise the system's mathematical model is. Thus, its development can be rather complicated and time-consuming. This adds to the computational weight, and hence is less tractable in any context where prompt adaptations are needed [4-5]. Microgrid systems have become significantly complex owing to the current challenges, often integrating diesel generators, Battery Energy Storage (BES), and solar and wind energy. Solar and wind energy require rigorous management systems to guarantee a reliable supply of electricity because of the inherently volatile nature of these sources of energy. Advanced control strategies are required for coordinating multiple sources of energy and storage systems to assure optimal performance as well as maintaining grid stability [6-7]. Real-time analysis becomes imperative towards effective management because traditional management systems struggle to deal with the massive amounts of data being generated [8]. MPC methods have shown promise as a method for resolving challenging optimization issues in microgrid management. Compared to conventional mathematical techniques, these methods are more efficient in producing optimal solutions.

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They are especially helpful in situations were. Algorithms can improve efficiency during high consumption periods by modifying resource allocation based on real-time demand projections [9]. These methods can minimize emissions from fossil fuels and drastically lower operating costs by optimizing the dispatch of different energy sources. as the need for more sustainable and effective energy solutions increases. To improve operational efficiency, new systems need to track integrated energy sources' performance properly. Sophisticated algorithms ought to be able to adjust to variations in the supply and demand of energy, guaranteeing optimal performance in a range of scenarios. By improving efficiency and reliability, these systems can position microgrids as viable alternatives to traditional energy systems, contributing to a more sustainable energy future [10].

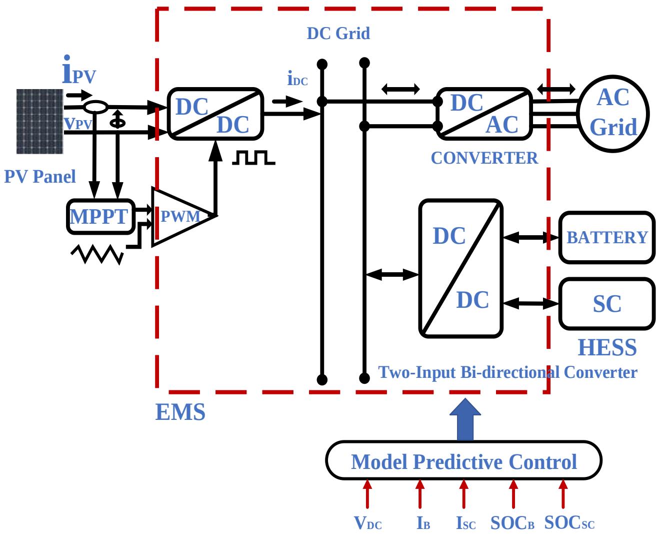

Figure 1. Energy management system outline

To achieve the best economic performance in microgrid operating costs, MPC optimization is proposed in [11], and to achieve optimal home network microgrid functionality, MPC rolling phase technology is proposed in[12].Three crucial criteria affect the amount of effective power needed to maintain a balanced power flow at the DC connection: The analysis identifies three distinct categories of power: *(i)* oscillatory power, resulting from the oscillatory component of AC power in the DC link; *(ii)* average power, primarily determined by average changes in average load and/or renewable power requirements; and *(iii)* transient power, primarily caused by abrupt changes in load and/or renewable power. With the utilization of these power components, the grid-interactive hybrid energy storage system (HESS). This was to be achieved by "forecasting the HESS voltage, which is defined as the total of the OCV plus the dynamic voltage of the ohmic resistance while current flows [13].

$$V_{bat(k)} = OCV\,(SoC_{(k)}) + RI_{(k)} \tag{1}$$

To do this, it was assumed that have predictions for the HESS voltage, which is the sum of the OCV plus the voltage of the ohmic resistance while current flows.

$$V_{bat(k)} = 3.381SoC_{(k)} + 0.048I_{(k)} + 50.482 \tag{2}$$

The following functions should be followed by the power flow balance:

$$\eta_g P_{grid(k)+} P_{solar(k)} = P_{bat(k})+((1/\eta_i - \eta_g)\sigma(_k)+\eta g)P_{load(k)+} P_{sc} + P_{w(k)} \tag{3}$$

P_{solar}, P_{bat}, P_{sc}, P_{grid} are the utility grid powers, the battery unit, the supercapacitor unit, and the RES, in that order. The sum of the DC and AC load powers is the power $P_{l(t)=} P_{dcl(t)} + P_{acl(t).}$ The net power required to control the DC link voltage (Vdc) is provided by (2) based on (1).

$$P_{w(k)\geq} 0 \tag{4}$$

To maintain the power balance at the DC link, Pw is the effective power flow from multiple sources/sinks, including RES, HESS, and the utility grid. The effective current demand at the DC connection for the three powers may be found by using (2)[14].

$$P_{solar(k)}) - P_{w(k)} \geq 0 \tag{5}$$

$$P_{grid(k)} - (1 - \sigma(k))P_{load(k)} \geq 0 \tag{6}$$

$$SoC_{min} \leq SoC_{(k)} \leq SoC_{max} \tag{7}$$

$$V_{bat(k)} = 3.381SoC(_k) + 0.048I(_k) + 50.482 \tag{8}$$

$$P_{bat(k)} = V_{bat(k)} I_{(k)} \tag{9}$$

Considering power limits for charging/discharging process

$$P_{batmin} \leq P_{bat(t)} \leq P_{batmax} \tag{10}$$

It can be replaced with the following equation:

$$1 - SoC(_k) \leq \delta(_k) \leq 1000(1 - SoC(_k)) \tag{11}$$

$$P_{w(k}) \leq P_{solamax(1 - \delta(k}))) \tag{12}$$

It's crucial to recognize that the problems in (1) through (12) above are mixed integer nonlinear problems that can be resolved with the help of the MPC technique. Use the average PV generation, load consumption, and unit energy price profile at time k as the forecast information at the step. The simulation operation is already at its best throughout most of the day [15]-[17]. This study examined current microgrid energy management techniques. *Table 1* below shows the parameters for Model predictive controller.

Table 1. Parameters for Model predictive controller

Parameters	Values
Steady voltage of the battery	686.594 V
Internal resistance of the battery	17.13x10e-3Ω
Resistances to polarization	3.50 x10e-3
Battery capacity	41 Ah
Nominal capacity of the battery	39 Ah
The capacity exponentially	1 Ah
Voltage at full charge	3.95 V
Standard voltage	3.6 V
Voltage exponential	3.9 V
Nominal discharge current	13.67 A
Discharge current nominal $SoC_{(min)}$ / $SoC_{(max)}$	0/1
System-wide power cost without load (kW)	-5
Max power at discharge [kW]	-5
Max power of charging [kW]	5kW
Max power [kW] at load the lowest power [kW] of the load	3kW
Max solar power in kW the highest SoC level possible the bare minimum of SoC	2.2kW

2. RESULTS AND DISCUSSION

The solar power generation at distinct temperatures and irradiation levels throughout a day. At *t=1* sec, the hybrid energy storage system plays a crucial role in providing power to compensate for the shortage in the utility grid's load. During this time, the battery, supercapacitor, and utility grid collaborate to supply power to meet the shortfall in demand until the battery's state of charge drops below a specific threshold. The following part presents the suggested energy management scheme's dynamic and steady-state performance under various operating modes. Depending on the SoC condition of the energy storage devices, there are three sub-states in each power mode:

1. State-1: SoC_B>L and SoC_{sc}>L
2. State-2: SoC_B<L and SoC_{sc}>L
3. State-3: SoC_B>L and SoC_{sc}<L

In *state-1*, the battery assists in supplying power to the utility grid's deficit load until state of charging of the battery (SoC_B) falls below a certain threshold (SoC_B<L). At *t=1* sec, the management of the DC link voltage and the regulation of battery current are successfully achieved, as shown in *figure 2*. In summary, the hybrid energy storage system plays a crucial role in compensating for the shortfall in the utility grid's load, with the suggested energy management scheme effectively managing the various operating modes based on the SoC conditions of the energy storage devices.

In *state-2*, the battery's State of Charge (SoC_B) is intentionally created to drop below a set level at $t=t_1$. This causes the battery's reference power to go to zero. Consequently, in a steady state, the utility grid provides the entire deficit load power, while the supercapacitor packs absorb the transient power shift, resulting in a gentle shift in the V_{SC} current. Due to the fast-discharging nature of the supercapacitor, at *t=2* sec, the state of charge of the supercapacitor (SoCsc) falls below a certain threshold (SoCsc<L), as shown in figure 4. From the available data, it is evident that the DC link voltage fluctuations have been much lessened by the high-power density supercapacitor and their efficient management, as seen in *figure 5*. The hybrid energy management system that has been presented has the potential to extend the battery's lifespan by reducing the fluctuations in the DC connection voltage and, consequently, the amount of current that is drawn from the DC link.The dynamic efficacy of the suggested energy management plan in various modes, which is impacted by variations in the power of renewable energy sources. Depending on the load circumstances and the availability of RES power, it automatically switches between modes. Depending on the energy storage devices' state of charge (SoC), the supercapacitor and battery either supply or absorb transient power surges to offset abrupt variations in renewable energy sources (RES) and/or demand. At the DC side, the surplus average power is used to feed energy back into the utility grid or to replenish energy storage deviceshe simulation findings validate the theoretical suitability of the suggested topology with passive HESS. The simulation results just illustrate the sharing of photovoltaic electricity on days with partial cloud cover by decreasing the peak power output of the PV system. Hybrid energy storage devices, which integrate batteries and supercapacitors, can effectively reduce stress levels. In comparison to other current techniques, the suggested MPC based Energy Management System (EMS) for microgrids exhibits a number of advantages, especially with regard to flexibility, constraint handling, and dynamic performance. In terms of overshoot/undershoot, settling time, and tracking precision, MPC performs better than conventional PID and PI controllers. Compared to PID and PI controllers, which do not handle constraints as simply, MPC controllers manage operational restrictions more effectively because they can directly include constraints into their optimization framework. But while PID and PI controllers are easier to develop and implement than MPC, they are nevertheless valuable in simpler settings or in situations where computational resources are few.

MPC often has lesser control complexity and does not require a modulation stage, making it easier to implement than SMC while still offering effective constraint handling. SMC is recognized for its resilience against system uncertainties and disruptions. Because they are easier to design and need less computing power, rule-based systems have occasionally been demonstrated to perform better than MPC instances. They might not, however, be able to manage dynamic situations as well as MPC. Although MPC has several benefits, its application in resource-constrained contexts may be limited due to its greater computing requirements.

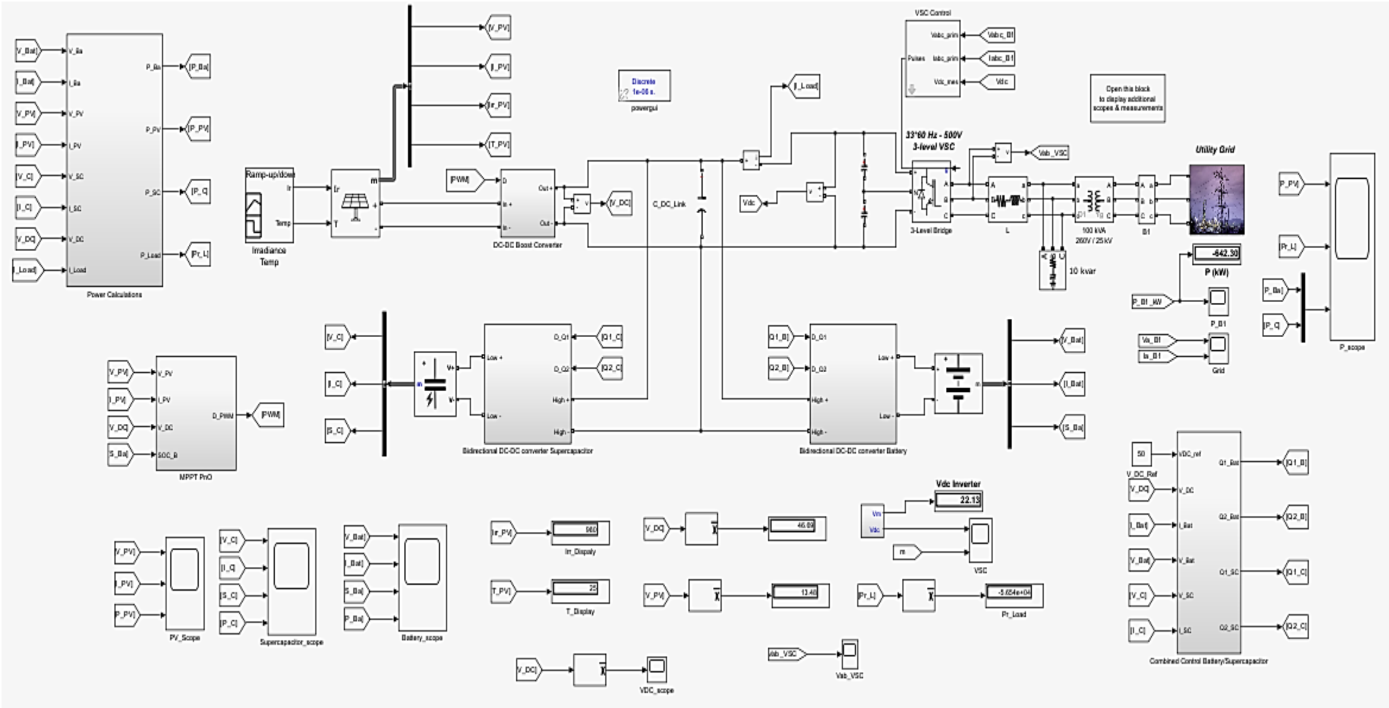

Figure 2. Simulink Implementation of MPC-based energy management

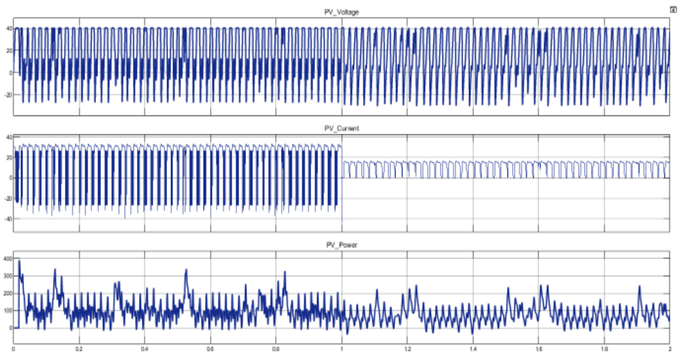

Figure 3. Output waveforms of PV voltage, PV current and PV power

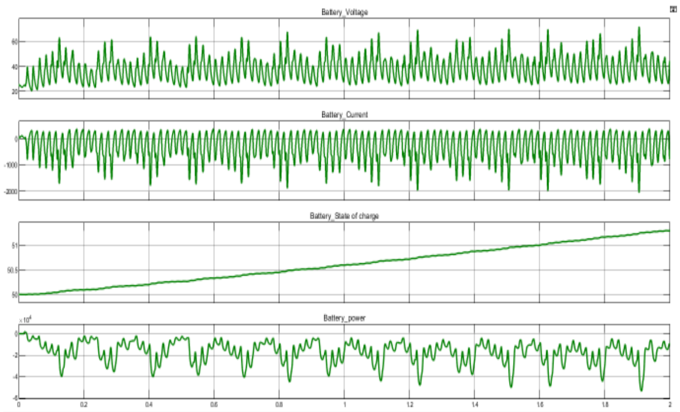

Figure 5. Output waveforms of Voltage, Current, state of charge and Power of Battery

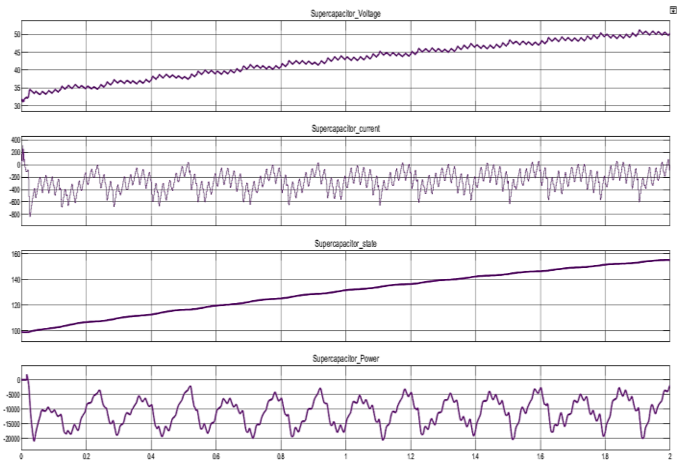

Figure 4. Voltage Current and Power waveforms of supercapacitor

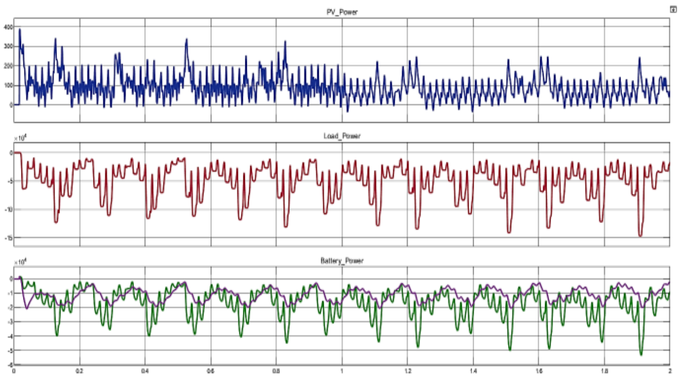

Figure 6. Power curves of PV, Load, Battery and Supercapacitor

By pre-calculating control rules for operating zones, explicit MPC can lower processing costs and enable faster runtime assessments. However, because several control zones must be stored, this strategy may result in higher memory needs. When compared to traditional controllers, experimental tests have shown that MPC performs better in terms of tracking accuracy, dynamic response, and robustness under varied situations. However, to ensure that the controller selection is in line with the resources available and performance expectations, much attention should be given to the unique operational requirements and limits of the microgrid system being managed.

Table 2. Represents the comparative study of optimal PID control and MPC

Performance parameters	Optimal PID	MPC
Tr (sec.)	6.085	2.9955
Ts (sec.)	10.659	5.7333
Mp%	1.72	0
IAE	5.81	3.046
ITAE	20.39	5.317

It is important to bring out the optimal performance of the MPC controller which incorporates several eligible parameters that have to be chosen carefully. Some of these factors are control interval, prediction horizon, control horizon, general tuning factor, weights on inputs and outputs. The design of the MPC controller is supported by the MPC toolbox in MATLAB. In this paper, MPC controller is added on top of each case study in order to improve the functional behavior of the Proportional-Integral-Derivative Controller (PID) controller. This way, two different controllers are applied to the plant and the time-domain step response is calculated to allow an analysis to be done. In calculating the performance indicators, implementation of performance metrics numerical analysis is done. Whereas, on the response curves of the systems, a qualitative comparison is done.

3. CONCLUSION

This paper presents a comprehensive analysis of a hybrid photovoltaic (PV) system that integrates a battery and a supercapacitor, as well as active power management using MATLAB/Simulink software for a novel topology. This work evaluated the merits and demerits of Hybrid Energy Storage Systems (HESS) for active photovoltaic power regulation. The utilization of supercapacitors in active PV power regulation does not result in increased costs, as it has been proven that their implementation on the load side reduces the cost associated with the storage system. A novel design for HESS was proposed to efficiently distribute photovoltaic (PV) electricity and mitigate PV peak power. The suggested passive HESS has been built by coupling the PV module with MPPT, battery, and the supercapacitor module. The addition of the feedback mechanism by the Model Predictive Control (MPC) partially reduces the unpredictability of the microgrid system. The simulation findings demonstrate that this topology may be used experimentally and utilized to improve the efficiency of HESS. Future research will examine various HESS topologies, control schemes, and grid linkages.

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