A MODEL PREDICTIVE CONTROL STRATEGY FOR RENEWABLE ENERGY BASED AC MICROGRIDS TO IMPROVE POWER QUALITY

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Abstract – The development of Micro Grid (MG) is an advantageous option for integrating rapidly growing renewable energy. However, the stochastic nature of renewable energy and variable power demand has created many challenges like unstable voltage/frequency and complicated power management and interaction with utility grid. Traditional cascade control has major drawbacks like the control structure is complicated with multiple feedback loops and Pulse Width Modulation (PWM) modulation, which leads to slow dynamic response. Further, the tuning of the proportional Integral Differential (PID) parameters is time consuming, which makes the controller not easy to implement. As a result, traditional cascade control with its fast transient response and flexibility to accommodate different constraints has huge potential in MG applications.

This project was implemented by novel model predictive control strategy without involving any PID regulators for practical renewable energy based AC MGs. By controlling the bidirectional Buck-Boost converters of the Battery Energy Storage System (BESS) based on the Model Predictive Power Control (MPPC) algorithm, the fluctuating output from the renewable energy sources can be smoothed, while stable DC-bus voltages can be maintained as the inverters inputs. Further, the parallel inverters can be controlled by using a combination of the Model Predictive Voltage Control (MPVC) scheme and the droop method to ensure stable AC voltage output and proper power sharing. The proposed methods have tested on MATLAB/Simulink platform.

Key Words: Micro Grid, Pulse Width Modulation, Proportional Integral Derivative, Battery Energy Storage System, Model Predictive Power Control, Model Predictive Voltage Control, Maximum Power Point Tracking, Solar Tracker, Distributed Generator.

1. INTRODUCTION

Renewable energy sources like Photovoltaic, Wind and Hydro can provide electricity to the microgrid, based on the availability of the sources. For decades, cascade linear control has dominated the power electronic control techniques. However, this approach has major drawbacks. First, the control structure is complicated with multiple feedback loops and Pulse Width Modulation (PWM), which leads to slow dynamic response. Second, the tuning of the Proportional Integral Derivative (PID) parameters is time-consuming, which makes the controller not easy implement. In a practical AC Microgrid, fluctuating output from renewable energy sources can cause oscillations in DC – bus voltage, which in turn, may further deteriorate the power quality on the AC side.

The problems with PID controllers are multiple feedback loops, time consuming PID tuning and fluctuating output. It is very much essential to address the problems of PID controllers, so that Model Predictive Control (MPC) schemes are preferable.

The MPC scheme, in which the optimal switching state of the power converter is determined according to a specified cost function, has been adopted to obtain better performance, A MPVC is incorporated with droop method to control the parallel inverters for load sharing, and a MPPC is developed to maintain the DC - bus voltages and smooth the Photovoltaics output. In proposed system, multiple power converters replace all the traditional cascade voltage or current feedback loops by using MPC approaches. Therefore, to reduce the power quality issues, we are implementing MPC strategy instead of PID controllers in our project to enhance power quality in AC Microgrid.

1.1 OBJECTIVE

To reduce the power quality issues in AC microgrid by adopting Model Predictive Power Control (MPPC) and Model Predictive Voltage Control (MPVC) schemes. MPPC schemes maintain the DC bus voltages and smoothen the Photo Voltaic (PV) output, MPVC scheme controls the parallel inverters for load sharing.

2. MODEL PREDICTIVE CONTROLLER FOR MICROGRIDS

2.1 PROBLEM DESCRIPTION

The problems with PID controllers are multiple feedback loops, time consuming PID tuning and fluctuating output. It is very much essential to address the problems of PID controllers, so that MPC control scheme are preferable.

In Proposed system, multiple power converters replace all the traditional cascade voltage or current feedback lops by using MPC approaches. The proposed method presents a smoother and faster transient performance than traditional method due to better voltage control capability of MPVC. A MPPC generates larger current to reduce voltage oscillations in order to stabilise the DC bus voltage.

2.2 WORKING OF MPC

The proposed method consists of a MPPC and MPVC scheme By controlling the bidirectional buck-boost converters of the battery energy storage of the Battery Energy Storage System (BESS) based on the MPPC algorithm, the fluctuating output from the renewable energy sources can be smoothed. While stable DC bus voltages can be maintained as the inverter inputs. Then, the parallel inverters are controlled by using a combination of the MPVC scheme and the droop method to ensure stable AC voltage output and power sharing.

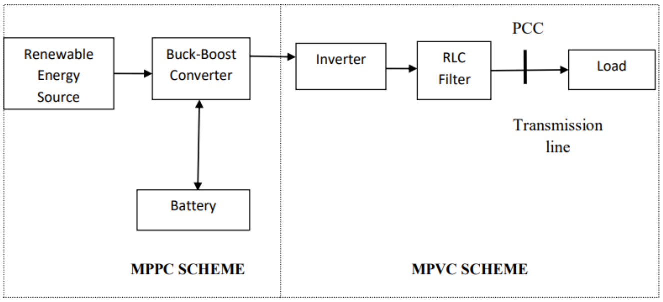

Fig -1: Block Diagram of MPC System in Microgrid.

2.2.1 MPVC OF PARALLEL DC-AC INVERTERS

The main usage of MPVC scheme incorporated with droop method is to control the parallel inverters for load sharing.

For a single inverter based isolated AC system, the target is to control the inverter to establish a stable and as well as a balanced output voltage for the loads.

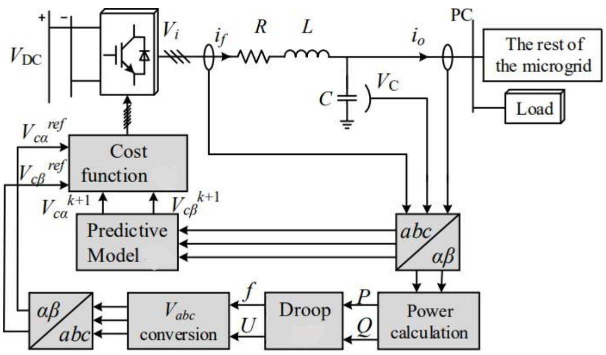

Fig -2: Block Diagram of MPVC.

In MPVC, the voltage across the filter capacitor is control objective. According to the circuit shown in the figure-2. The voltage across the filter capacitor as follows.

$$C\frac{dV_c}{dt} = I_c = I_f - I_0$$

The mathematical model of an Inverter can be written as

$$V_i = I_f R + L\frac{dI_f}{dt} + V_c$$

A cost function that measures how well the network predicts outputs on the test set. Cost function gives the lowest Mean Squared Error (MSE), which is the sum of the squared differences between the prediction and true value.

The capacitor voltage controlled by the cost function and it is formulated as

$$J_v = \left(V_{c\alpha}^{ref} - V_{c\alpha}^{k+1}\right)^2 + \left(V_{c\beta}^{ref} - V_{c\beta}^{k+1}\right)^2$$

where $V_{c\alpha}$ and $V_{c\beta}$ are the real and imaginary components of the capacitor voltage, respectively. Based on this cost function, the voltage vector that generates the least value of J_V will be applied during the next sampling period. Because the α and β components are tightly controlled, the $\boldsymbol{V}_c$ can track its reference. Thus, stable and sinusoidal voltage can be established. For parallel inverter based ac system, droop method is commonly adopted to achieve power sharing between DGs without interactive communication lines.

$$\begin{cases} f_j = f^* - m_j \cdot (P_j - P^*) \\ U_J = U^* - n_j \cdot (Q_J - Q^*) \end{cases}$$

where j is the index indicating each inverter. f_j and U_j are the actual frequency and voltage, f_* and U_* the nominal frequency and voltage, P_j and Q_j the average active and reactive power, P_* and Q_* the nominal active and reactive power, and m_j and n_j the droop slopes.

Inspired by the effectiveness of Voltage control of MPVC and the load sharing capability of droop method, the new parallel inverter control strategy is developed as shown in the figure-2. The traditional voltage and current feedback loops have been replaced by MPVC scheme.

2.2.2 MPPC OF BIDIRECTIONAL BUCK-BOOST CONVERTERS

The aim of the MPPC strategy is to maintain the DC bus voltage and smoothen the PV's output. Here, the BESS is to compensate the power gap caused by the PV output and the load demand through maintaining the DC bus voltage.

Since the power supplied or absorbed by BESS is actually controlled by switching the buck-boost converter, it is necessary to obtain the effect of switching states on power absorbed/ supplied. Figure-3 shows the circuit of BESS including the battery and the converter.

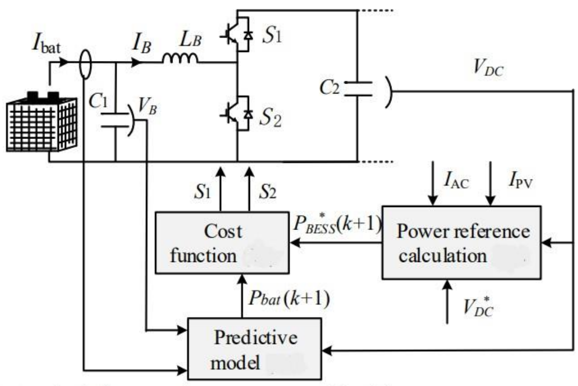

Fig -3: Block Diagram of MPPC.

- Boost operation – S2 ON, S1 OFF – Battery discharge.
- Buck operation – S1 ON, S2 OFF – Battery charge.

If S2 is switching (1 or 0) and S2 is kept OFF, it operates in boost mode. The battery discharges to supply power. On the contrary, if S1 is switching (1 or 0) and S2 is maintained OFF, it operates in buck mode.

In boost mode, the circuit operation as

$$S_2 = 1, S_1 = 0, V_B = L_B \cdot \frac{dI_B}{dt}$$

In buck mode, the circuit operation as

$$S_2 = 0, S_1 = 1, V_{DC} - V_B = L_B \cdot \frac{dI_B}{dt}$$

The battery output power can be predicted as

$$P_{bat}(k+1) = |I_B(k+1) \cdot V_B(k)|$$

The required power by BESS to keep the power balance within the Microgrid can be calculated as

$$P^*_{BESS} = |I_{DC} \cdot V^*_{DC}|$$

The cost function makes the power balance in Microgrid as

$$J_P = |P^*_{BESS}(k+1) - P_{bat}(k+1)|$$

By means of cost function, the DC bus voltages can be maintained stable as the inputs for the parallel inverters.

3. SIMULATION RESULTS

The MPC strategy for AC micro grids is modeled and implemented in both MATLAB/Simulink platform. To verify the proposed method with practical consideration, the system parameters are considered as follows.

PARAMETERS	VALUES
Module maximum power	549 W
Array parallel module Strings	66
Array series connected modules	10
BESS nominal voltage	500 V
BESS rated capacity	1600 Ah
DC- bus voltage	1 kV
Inverter rated frequency	50 Hz
Inverter phase voltage	380 V
Filter inductance	2 mH
Filter capacitance	250 μF
DG-1 and DG-2 ratings	45 kVA, 42 kVA
Line resistance R_{gl1} and R_{gl2}	0.05 Ω, 0.04Ω
Line reactance L_{gl1} and L_{gl2}	0.6 Ω, 0.48 Ω

In this project work, a new MPC strategy has been proposed for AC micro grids with PVs and energy storage. The method addresses the problem of traditional cascade linear control including complicated feedback loops, slow dynamics and time- consuming PID tuning. By implementing MPC strategies we can enhance power quality in AC micro grids.

3.1 SIMULINK MODEL

The Simulink model for MPC implemented AC micro grids is shown here.

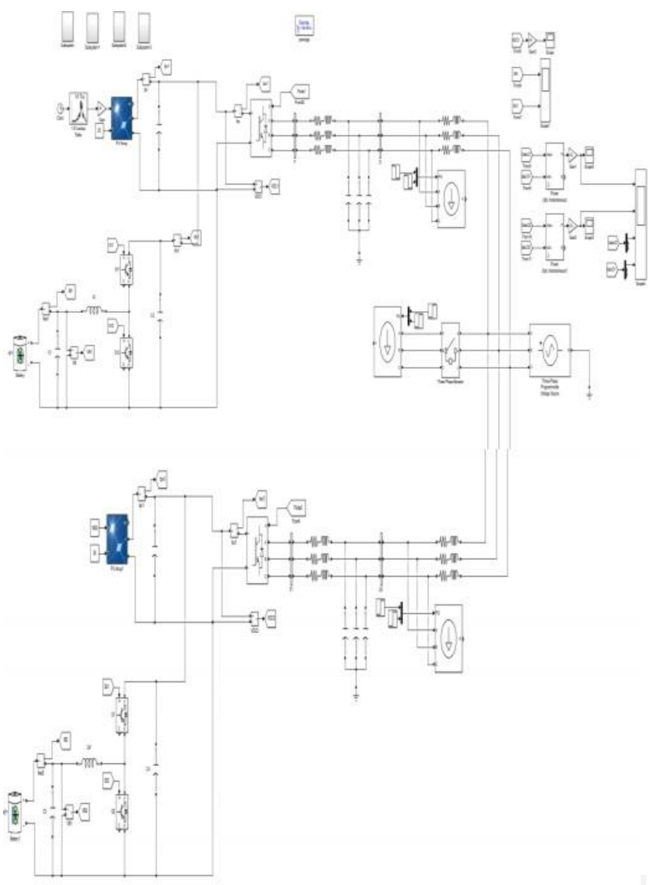

Fig -4: Simulink Model for MPC Implemented AC Microgrid.

3.2 SIMULINK RESULTS

Here by the usage of PID controllers, power quality issues are occurred. Where, by adopting MPC strategy instead of PID we can enhance the Powe Quality of the system. These results have shown here.

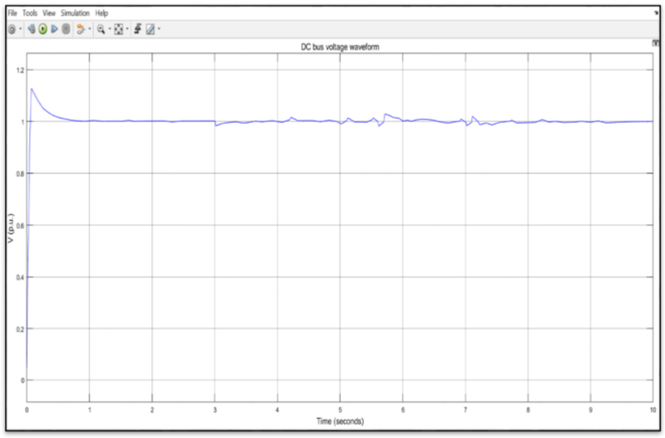

Fig -5: DC Bus Voltage of DG in Traditional Method.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 11 | November - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

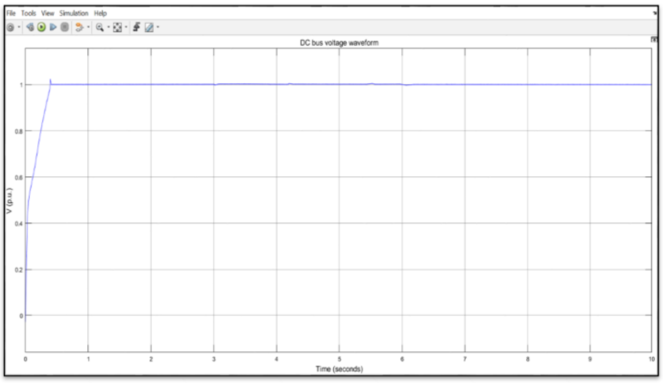

Fig -6: DC Bus Voltage of DG in Proposed Method.

Figure 5 and 6 shows the comparison between the DC bus voltage of traditional and proposed method. Clearly, under various solar irradiation and load condition, the DC bus voltage is tightly controlled by using the proposed method. This demonstrates the excellent control performances of the proposed MPPC method.

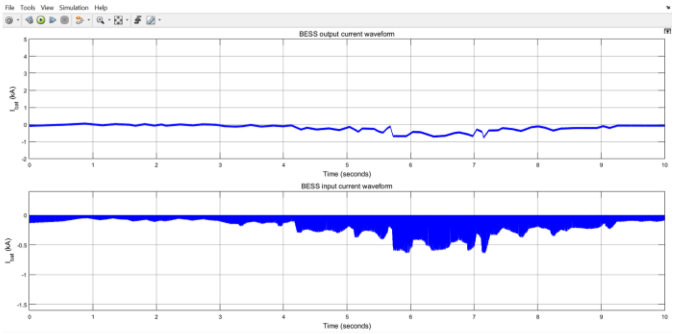

Fig -7: BESS Current Waveform in Traditional Model.

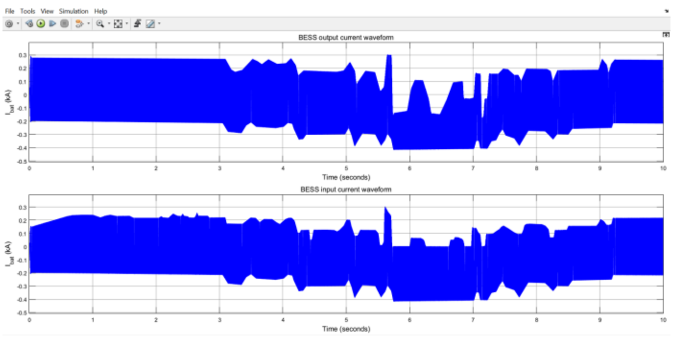

Fig -8: BESS Current Waveform in Proposed Model.

Figure 7 and 8 shows the response of the BESS to such fluctuating solar PV output and variable power demand. MPPC generates larger current to reduce Voltage oscillations in order to stabilize the DC bus voltage.

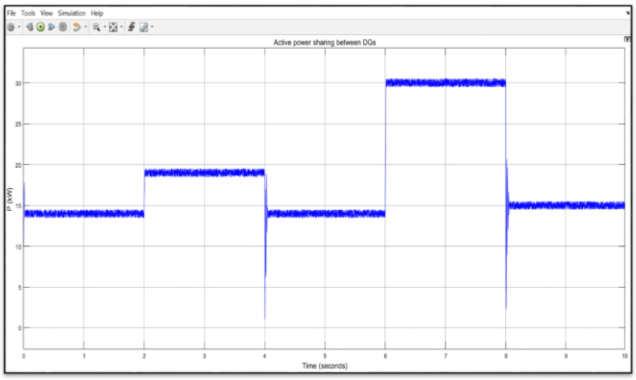

Fig -9: Active Power Sharing between DGs in Traditional Model.

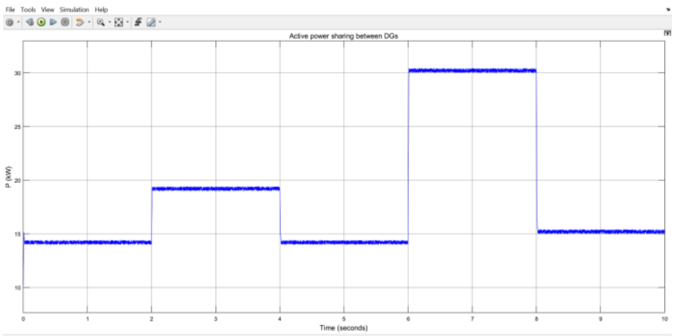

Fig -10: Active Power Sharing between DGs in Propsosed Model.

Figure 9 and 10 compares the power sharing between the proposed method and traditional method. It can be seen that, for both methods, the parallel inverters can adjust output automatically to meet the varying power demand because of the droop method. But, the active power by using the proposed method presents a smoother and faster transient performance than that by using a traditional method, due to the better voltage control capability of MPVC.

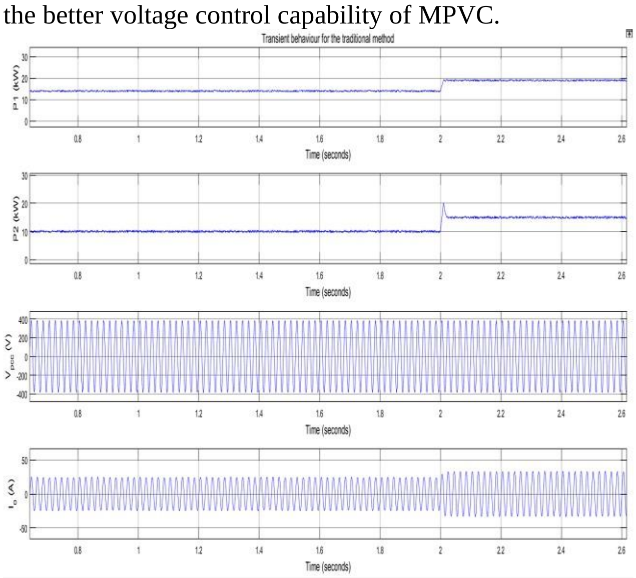

Fig -11: Transient Behavior of an AC Microgrid in Traditional Model.

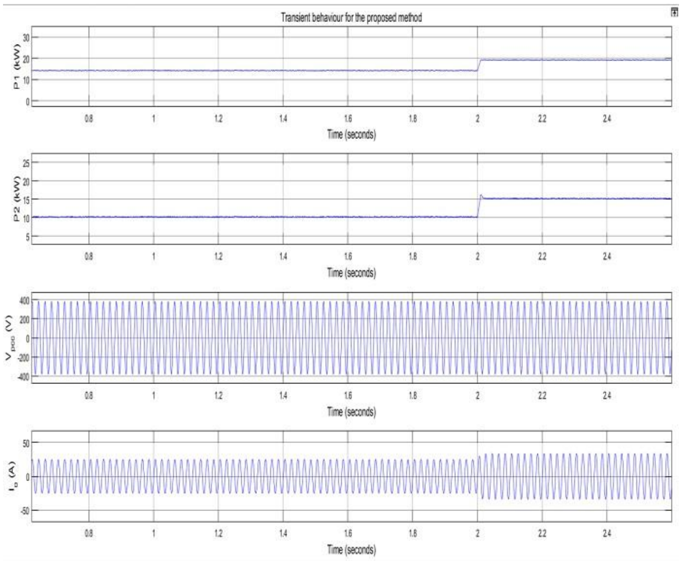

Fig -12: Transient Behavior of an AC Microgrid in Proposed Model.

Figure 11 and 12 presents the system transient behavior. As we can see, the inverters can share their output in a fast and safe manner when load changes. Changes in the load occur due to the changes in current obtained from the PV array. Meanwhile, the voltage for the load in very stable and sinusoidal.

4. CONCLUSION

In this journal, a new MPC strategy has been proposed for AC micro grids with PV's and energy storage. This method addresses the problems of traditional cascade linear control including complicated feedback loops, slow dynamics and time-consuming PID tuning. Accordingly, a MPPC is developed to maintain the DC voltage and smooth the PV output, while a MPVC is incorporated with droop method to control the inverters for load sharing. The proposed control strategy has been validated in both Simulink simulation and Real-time laboratory platform. The test results verified that, under fluctuating power generation and various load condition, the control scheme maintain the DC- bus voltage with much less oscillations. Moreover, the power sharing inverters is faster and smoother, while the AC voltage is kept stable.

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of people who made it possible, whose constant guidance and encouragement crowned our efforts with success. It is a pleasant aspect that we have now the opportunity to express our gratitude for all of them.

It is with immense pleasure that we would like to express our indebted gratitude to our Guide **Mr. E Nagabhushana, Assistant Professor, Electrical Power System**, who has guided us a lot and encouraged us in every step of the journal work. We thank him for the simulating guidance, constant encouragement and constructive criticism which have made possible to bring out this journal work.

We thank all other faculty and non-teaching staff, and our friends who had directly or indirectly helped and supported us in completing our research in time.

We also express our sincere thanks to **MANAGEMENT of PVKK institute of Technology** for providing excellent facilities.

Finally, we wish to convey our gratitude to our family who fostered all the requirements and facilities that we need.

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BIOGRAPHIES

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