Predictive control for Islanded mode DG with Voltage Source Inverter

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Abstract — This paper explains the predictive control of three phase islanded mode VSI interfaced DG. The controller aims are twofold: a) Maintain the nominal voltage and frequency, b) Supply the required load power. The inner current control loop is Predictive control- Finite Control Set Model Predictive Control (FCS-MPC), using one step ahead predicting algorithm-improving the dynamic response. The power electronic converters are made up of switches, which are discrete in nature-i.e., either ON or OFF. Conventional MPC is simplified by taking advantage of this nature and converts the actual optimisation problem into evaluate and choose the best solution type problem. Because of the limited number of switching states, the evaluation is quick and can be considered to an online optimal control.

Keywords: FCS-MPC; Islanded mode VSC; Renewable energy; Microgrids; Power Conversion.

1. INTRODUCTION

Distribution networks are becoming active, with inclusion of Distribution Generation. Because of active participation of the consumer side, power flows both, from and to the consumer. Around the globe, Solar power generation is being encouraged more along with wind power generation.

Various inverter topologies for solar and wind based renewable systems are explained in [1]. Control involves reference current generation to have real, reactive power control and a current controller which implements the command to enable desired function. Overview of some current control techniques is given in brief in [1] and [2] gives brief idea of the control of Voltage Sources Converters with control in Synchronous Reference Frame Theory (SRFT) (d-q)in [3] and Instantaneous Reactive Power Theory (IRPT) (α − β) frames. Since renewable energy sources are getting more popular [4], the case of Islanded mode of operation of DG is a hot research topic.

Once reference currents are generated, they have to be tracked properly; there are many controllers available and some of them are PI control and Hysteresis control which are more traditional controllers; because of various drawbacks of the aforementioned controllers advanced controllers like Sliding Mode Control, State Feedback Control, Deadbeat Control, Fuzzy Logic Control, Neural Network Control, Model Predictive Control are introduced for solving the problems and improving dynamic response of the overall system. Various linear and non-linear control techniques are compared in [5], [6] and [7].

A new set of control called predictive control is growing in popularity and various predictive controls are explained in [8],[9] and [10]. It is also to be noted that MPC is the only advanced control, to be applied widespread in industrial application [10]-process industries.

Discrete time MPC and Matlab implementation of the same are explained in [10] and [11]. With various reference current generation application of MPC for grid tied converters are explained in [12] and [13].

An alternative approach is to go for modified converter structures, instead of using advanced controllers.
like MPC and this is explained for application of DSTATCOM for power quality improvement in [14-17].

One of the biggest drawbacks of conventional MPC is that it requires large numbers of computations and memory for finding out the optimal solution.

Even though MPC has very good dynamic response, this was a limitation and a major reason for not having control based on it for high frequency control like power electronics control. However, the power electronic converters are made up of switches which can either be ON or OFF-making it to be discrete. For a given converter, the number of switching possibilities are limited and this is the base for Finite Control Set MPC (FCS-MPC).

By limiting the search space to possible switching states, the online optimisation problem is reduced to a simple evaluation problem which is allowing MPC for Power electronic converter to incorporate its fast dynamic response.

Auto-tuning or re-tuning PI and adaptive band hysteresis control are existing in literature, but the optimality of it is not guaranteed. MPC, is based on the system model and so for varying system operating conditions, it gives optimal control and with FCS-MPC it is online optimal control.

In this paper, SRFT based FCS-MPC is used for Islanded mode control of VSC interfaced DG and for this paper, the source is taken as a Stiff DC voltage source which can be any DG source like PV or Fuel cell or batteries. Islanded mode control is important as in rural parts of many countries, where it is difficult to supply power through transmission lines-the stand alone DG system can provide power and electrify.

2. SRFT BASED FCS MPC CONTROL

Islanded mode DG feeding the load is given in Fig.1 and since most of the present loads are AC, an inverter is needed for the interface. Model Predictive Control (MPC) is self-explanatory with the name, as it incorporates the model of the system to predict state variables to control the desired objective.

The control action is given as an objective function for the controller and usually it is the reference current error as MPC is used for current control. As explained in Section I, power electronic switches can either be ON or OFF and for a two level three phase converter the number of possible switching states is $2^3=8$.

Fig.2 explains the general MPC scheme for Inverter control and the control can be made in $dq$ frame or $abc$ frame. Generally MPC is used for control in $abc$ frame and in this paper, it is used for control in $dq$ frame.

![Figure 1 Test system](image-url)
Objective function used for selection of the switching pulses is: 
\[ J = (i_d^k - i_d^{k+1})^2 + (i_q^k - i_q^{k+1})^2 \]

**Figure 2:** Model Predictive Control based Current Control of Three phase inverter

3. **Model predictive control for two level three phase inverter**

For a two level three phase inverter, we’ve total of 6 switches and we have \( n(\text{level})=2 \) and \( p(\text{number of phases})=3 \). This means that the total number of switching states is \( n \) to the power \( p \), which is \( 2^3=8 \). This is the application of discrete nature of power electronic converters, i.e., the switch can either be on or off at a given point of time and based on the converter configuration only one switch is on in a leg.

The voltage vectors in state space form is shown in Fig.3.

**Figure 3:** Voltage vectors of a 2level 3ph inverter

Brief algorithm for the FCS-MPC based current control is given as:
1. **Input acquisition**: Take the DC voltage measurement and AC current and voltage measurements.

2. **Reference current generation**: Generate the reference current in response to the system voltage and frequency. This has to include the generator limits and if limit is exceeded an auxiliary signal is sent for load reduction.

3. **One step ahead prediction**: For the current sample’s DC voltage value, predict what will be inverter output voltage for all possible switching states. V7 and V8 are zero vectors, so no need to calculate for them. Using this, find the future current value if this switching state is implemented for V1 to V6.

4. **Calculate Objective Function**: With Iref and Ik+1 in dq frame, calculate J which gives the current error for all switching states. The objective function taken in this paper is sum of squares of error in Id and Iq reference tracking. State giving minimal error is given as gating signals to the converter.

These four steps are repeated for our control period and because of the controller itself providing gating signals to the switches, there is no need for modulator, which also aids in faster control.

The control scheme for the Islanded mode DG is explained in Fig.4 and the results are given in Fig.5 and Fig.6.

First, the reference values are converted to equivalent values in dq frame voltages and it is then compared with the actual values to generate reference current in dq frame through PI control. This process is the outer loop of control which is followed by the inner current control loop, which is the proposed method-FCS MPC based current control.

![Figure 4: Control diagram for SRFT based FCS-MPC control for Islanded mode VSC](image)

For the given system to test the performance of the control system, we initially operate with 5kW load and increase the load to 10kW at t=0.5s. And then reduced back to 5kW at t=1.0s.

For the step change in load, we can see that the reference currents are tracked and it is shown in dq frame and abc frame.
Fig. 5 gives the tracking performance for current in dq frame and Fig. 6 gives the voltage and current measurements following a load change in abc frame. We can see that the system is able to supply the load while maintaining rated voltage, frequency and having negligible harmonic content while having very fast tracking of reference current.

**Figure 5** Controller performance a) Active and Reactive power, b) Idq tracking
**Figure 6:** Current and voltage during load increase at \( t = 0.5s \)

System parameters are: Nominal voltage is 415 V, 50 Hz; for time \( t = 0 \) to \( t = 0.5s \) \( P_{load} \) is 5kW, at \( t = 0.5s \) it is increased to 10kW and then reduced back to 5kw at \( t = 1s \).

## 4. CONCLUSION

Finite Control Set Model Predictive Control (FCS-MPC) is implemented for inverter control of Distributed Generation in islanded mode and the control tracks the required current meeting the power balance. The FCS-MPC control directly generates the switching pulses to control the power electronic converter and incorporates controller and modulator into single unit reducing delays. Non-linearities can be directly included in the FCS-MPC and the objective function allows one to include different functionalities. Also, with varying system operating conditions, the FCS-MPC works satisfactorily and one step ahead prediction is used in this paper and it works satisfactorily. Very fast tracking of the proposed FCS-MPC is useful for improving the transient response and high accuracy for varying system operating conditions is achievable. The future scope of this work are testing the performance of the proposed control for various operating conditions: different types of loads and parallel operation of DG's with different current reference algorithms.

## REFERENCES

[1]. Remus Teodorescu, Marco Liserre, Pedro Rodríguez, “Grid converters for Photovoltaic and Wind Power Systems”, 1st ed., John Wiley and Sons, Ltd., pp.68-73, 2011.

[2]. Prem Ponnusamy et al., "A New Multilevel Inverter Topology With Reduced Power Components for Domestic Solar PV Applications," in IEEE Access, vol. 8, pp. 187483-187497, 2020, doi: 10.1109/ACCESS.2020.3030721.

[3]. S. Mishra and P. C. Sekhar, “Real and Reactive Power Control of Voltage Source Converter based PV generating systems,” — Chapter-17, Solar Cell Nanotechnology, pp. 475–504, ISBN: 9781118686256, Wiley Press-Scrivener Publishing LLC, 2013.
[4]. Balathandayuthapani, S., Edrington, C. S., Henry, S. D. and Cao, J., "Analysis and Control of a Photovoltaic System: Application to a High Penetration Case Study", IEEE Systems Journal, Volume 6, pp.213-219, 2012.

[5]. J.S. Sakthi Suriya Raj, P. Sivaraman, P. Prem, A. Matheswaran, Wide Band Gap semiconductor material for electric vehicle charger, Materials Today: Proceedings, 2020, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.02.916.

[6]. Timbus, A., Liserre, M., Teodorescu, R., Rodriguez, P., Blaabjerg, F., "Evaluation of Current Controllers for Distributed Power Generation Systems", IEEE Transactions on Power Electronics, Volume 24, pages 654-664, 2009.

[7]. Malesani, L., Tomasin, P., "PWM current control techniques of voltage source converters-a survey", International Conference on Industrial Electronics, Control, and Instrumentation (IECON), Proceeding of IECON, Volume 2, 1993.

[8]. Mohamed, Y. A.-R. I., and El-Saadany, E. F., "An improved deadbeat current control scheme with a novel adaptive self-tuning load model for a three phase PWM voltage-source inverter", IEEE Transactions on Industrial Electronics, Volume 54, pages 747–759, 2009.

[9]. Cortes, P., Kazmierkowski, M.P., Kennel, R.M., Quevedo D.E., Rodriguez, J., "Predictive Control in Power Electronics and Drives", IEEE Transactions on Industrial Electronics, Volume 55, pages 4312 - 4324, 2008.

[10]. E. Ramprasath, P. Manojkumar, P. Veena “Analysis of Direct Current Motor in LabVIEW”, World Academy of Science, Engineering and Technology, 2015.

[11]. Prem, P., Sugavanam, V., Abubakar, A. I., Ali, J. S. M., C Sengodan, B., Krishnasamy, V., & Padmanaban, S. (2020). A novel cross-connected multilevel inverter topology for higher number of voltage levels with reduced switch count. International Transactions on Electrical Energy Systems, e12381.

[12]. P. Sivaraman & P. Prem (2017) PR controller design and stability analysis of single stage T-source inverter based solar PV system, Journal of the Chinese Institute of Engineers, 40:3, 235-245, DOI: 10.1080/02533839.2017.1303337

[13]. Sathiyanarayanan T. and S. Mishra, "Model Predictive Control of multi functional inverter for grid tied photovoltaic generators," IEEE 6th International Conference on Power Systems (ICPS), New Delhi, 2016, pp. 1-5, 2016.

[14]. E. Ramprasath, P. Manojkumar and P. Veena, "Induction motor analysis using labview", Proceeding on International Conference on Electrical Engineering and Technology, vol. 2, no. 5, pp. 498, 2015.
[15]. T. Sathiyarayanan, S. Mishra, “Synchronous Reference Frame Theory based Model Predictive Control for Grid Connected Photovoltaic Systems”, IFAC-PapersOnLine, Volume 49, Issue 1, Pages 766-771, 2016.

[16]. Dheepanchakkravarthy A Jawahar MR Venkatraman K Selvan MP and Moorthi S “Performance evaluation of FPGA-based predictive current controller for FLDSTATCOM in electric distribution system IET Generation”, Transmission and Distribution, Vol 13, No 19, pp. 4400 – 4409, 2019.

[17]. Dheepanchakkravarthy A Akhil S Venkatraman K Selvan MP and Moorthi S “Performance Analysis of FPGA Controlled Four-leg DSTATCOM for Multifarious Load Compensation”, Electric Distribution System Engineering Science and Technology an International Journal, Vol 21, No 04, pp. 692 – 703, 2018.

[18]. Dheepanchakkravarthy A Selvan MP and Moorthi S, “Alleviation of Current Quality Issues Caused by Electric Arc Furnace Load in Power Distribution System Using 3-Phase Four-Leg DSTATCOM”, Journal of the Institution of Engineers (India) - Series B, Vol 100, No 01, pp. 9 – 22, 2018.

[19]. Veerakumar Nnirmalkumar Sathishkumar Rajesh Novel harmonic elimination technique for cascaded h-bridge inverter using sampled reference frame, Journal of Theoretical and Applied Information Technology Vol. 58 No.2 2013

[20]. Dheepanchakkravarthy A Venkatraman K Selvan MP Moorthi S and Venkatakirthiga M, “Capability Evaluation of Four-leg DSTATCOM for Compensating Multifarious Loads”, Australian Journal of Electrical and Electronics Engineering, Vol 13, No 04, pp. 229 – 243, 2017.