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# Analysis of predictive control algorithm based PWM boost converter-based hybrid networks

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***Abstract*---**The Power Electronic Converter (PEC) interfacing with the Renewable Energy Hybrid System (REHS) like solar, wind, etc is very much important and its implementations and validations are most required to reduce the harmonic distortions, unity power factor, DC-link voltage regulation, and lower frequency with high-speed operations. The PEC is like us three phase Pulse Width Modulation of Bidirectional Power Electronic Converter (BPEC). This paper proposes the novel Tracking Controller based Predictive (TCP) with PI controller is implemented and validated using dSpace TMS 1102 Digital Signal Processor in the VSC. This processor is used to generate the reference currents and a novel tracking controller based predictive Instantaneous Reference Current Generation using Synchronous Detection Method (IRCGSDM), based on this controller the real time data are sensed through current and voltage transducer from 1KVA inverter realized and software (MATLAB Simulink) simulations are validated through MATLAB Software, This novel TCP controller algorithm achieved a fast response in the DC-link voltage regulation, reactive power compensation with unity power factor and nearest sinusoidal grid currents using predetermination of cost function minimization.

***Keywords*---**predictive, control algorithm, PWM boost, hybrid networks.

## Introduction

The REHS system gives more efficiency and high-power management when interfacing of bidirectional PWM VSC compares to the other DC/DC converter. It performs high power factor with unity and adaptable for any control algorithm


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with a bidirectional power transfer. This VSC gives in less harmonic distortions, unity power factor, DC-link voltage regulation, and lower frequency with high-speed operations. This PEC is very versatile and utilized in many different fields, such as static VAR Generators (SVG), Active Power Flow (APF), Distributed Energy Sources (DES), Unified Power flow controller (UPFC), and different high power energy storage systems with high DC power transmission and electrical drives of the On-Grid REHS.

Nowadays simplification and programmable and digital signal processing hardware's reducing the development time and cost of the equipments. Many digital advanced processors are used for this implementation of hardware setup and research of these REHS of PEC applications. The FMPC is implemented and investigated to CHB converter and explained about the small sampling time and admissible states with Dead-beat controller with Fuzzy logic is applied to VSC and attained different parameters[3].

Very high robotically, reliable and versatile technologies are utilized to modern electrical and electronic converters for generating the reference currents. These technologies are used to reduce the system size, cost and implementation time and overall performance of the PEC devices are increased and new logical FPGA torque and speed controller is developed [4]. Voltage balancing, Reactive power compensation and low frequency operations are achieved using predictive and different types of linear/non-linear controllers. Different types of reference current templates and regulations are achieved using the VSC [5-8].

This paper proposes has five sections: the first part explains about the different type control, interfacing and applications of PEC. The second part presents about the system description and mathematical model of VSC. The third part achieves the proposed tracking based predictive control algorithm. The fourth part attains validates the simulation results of hardware. The fifth part gives the conclusion of the proposed algorithm.

**System Description and Modeling**

The block diagram of the bidirectional power transfer between the REHS is shown in the Fig. 1(a). The AC and DC hybrid system is interfacing with BPEC is as shown in the Fig.1 (b). The instantaneous power is transfer from AC grid to DC grid and vice versa. The purpose of the tracking controller based predictive controller overcomes the ripples reduction in the BPEC power transfer between AC to DC grid vice versa. The input instantaneous input AC grid currents are achieved nearest sinusoidal with regulated DC link voltage using minimization of cost function using predictive tracking controller algorithm. The cost function is evaluated by predetermination and all the switching states and reference current templates are also minimized using this cost function. The AC grid voltages are connected to DC active/passive load through interfacing of BPEC IGBT converter with linear/ non-linear load connected in the AC grid with AC utility voltages are balanced and unbalanced conditions. In unbalanced distortions conditions the phase synchronization is required and it has been achieved through PLL block. $v_{g1}$, $v_{g2}$,$v_{g3}$ are AC utility grid voltages, $i_{g1}$, $i_{g2}$,$i_{g3}$ are AC instantaneous grid currents. $u_a$, $u_b$, $u_c$ are switching states of the converter. $V_o$ is the DC link voltage and r=$r_1$, $r_2$, r3 of the internal resistances, L=$L_1$, $L_2$ and $L_3$ are input filter, it has used for ripple rejection in the AC grid currents. C is the output filter capacitor, it has filter an AC ripples in the DC output using PI controller loop. The output equivalent circuit output is considered as passive load is $R_o$.

$$L\frac{di_{g1}}{dt} = v_{g1} - ri_{g1} - \frac{2u_1 - u_2 - u_3}{3}V_{dc}$$
$$L\frac{di_{g2}}{dt} = v_{g2} - ri_{g2} - \frac{2u_2 - u_1 - u_3}{3}V_{dc}$$
$$L\frac{di_{g3}}{dt} = v_{g3} - ri_{g3} - \frac{2u3 - u_2 - u_1}{3}V_{dc}$$

(1)

$$C\frac{dV_{dc}}{dt} = u_1 i_{g1} + u_2 i_{g2} + u_3 i_{g3} - \frac{V_{dc}}{R_{dc}}$$

(2)

Where

$$v_{g1} = V_m \, Sin\, \omega t$$
$$v_{g2} = V_m \, Sin(\omega t - 120^o)$$
$$v_{g3} = V_m \, Sin(\omega t + 120^o)$$

(3)

From the equation (1) matrix equations are found as follows

$$\dot{X} = AX + B$$

$$where \quad X = \begin{bmatrix} i_{g1} \\ i_{g2} \\ i_{g3} \end{bmatrix}$$

(4)

$$A = \begin{bmatrix} r/L & 0 & 0 & m_1/L \\ 0 & r/L & 0 & m_2/L \\ 0 & 0 & r/L & m_3/L \\ u_1/C_{dc} & u_2/C_{dc} & u_3/C_{dc} & 1/(R_{dc}C_{dc}) \end{bmatrix}, \quad B = \begin{bmatrix} v_{g1} \\ v_{g2} \\ v_{g2} \\ 0 \end{bmatrix}$$

**Design of the three phase PWM boost Converter**

A three phase PWM FEC was designed with the following specifications: The AC input voltage is $v_{g123(RMS)}$ =40V, AC line frequency=50Hz, maximum output power is 480W, $R_{dc}$=40Ω, Output DC link Voltage = 120V, the AC minimum voltage for

DC voltage regulation is 21V, efficiency is considered as η ≥ 94%. The boost factor of the give three phase boost FEC is given by

$$M=\frac{V_{dc}}{V_{in}}=\frac{120}{40}=3 \quad (4)$$

The DC link voltage $V_{dc}$ is selected as more than as follows equation

$$V_{dc}=\frac{3\sqrt{3}V_m}{\pi}\cos\alpha \quad (5)$$

The ripple of the input inductor current is choosen as 10% of the current riple, so the riple current is $\Delta i_{Li}=\frac{10}{100}\times\frac{P_{dc\_\max}}{V_{in\_\min}}$, $\Delta i_{Li}=2A$ and the input filter resistance(r) is consider as 0.03Ω. The design of the input inductor and capacitor values are calculated using the duty ratio and ripple current, switching frequency is 10Khz, and switching period is considered as $t_s$ = 10ms, the input inductor and output capacitor is calculated as follows.

$$L=\frac{V_{g(rated)}.(V_{dc}-V_{g\_\min})}{\Delta i_L f_s V_{dc}}=\frac{40(110-15)}{2\times 10e^3\times 110}=1.727\text{mH}\approx 2\text{mH}$$

$$C_{dc}=\frac{2*\frac{P_{dc\_\max}}{\eta_{dc}}.t_s}{V_{dc}^2-V_{dc\_\min}^2}=\frac{2*\frac{300}{0.94}10e^{-3}}{110^2-90^2}=1.595\text{mF}\approx 2000\mu\text{F}$$

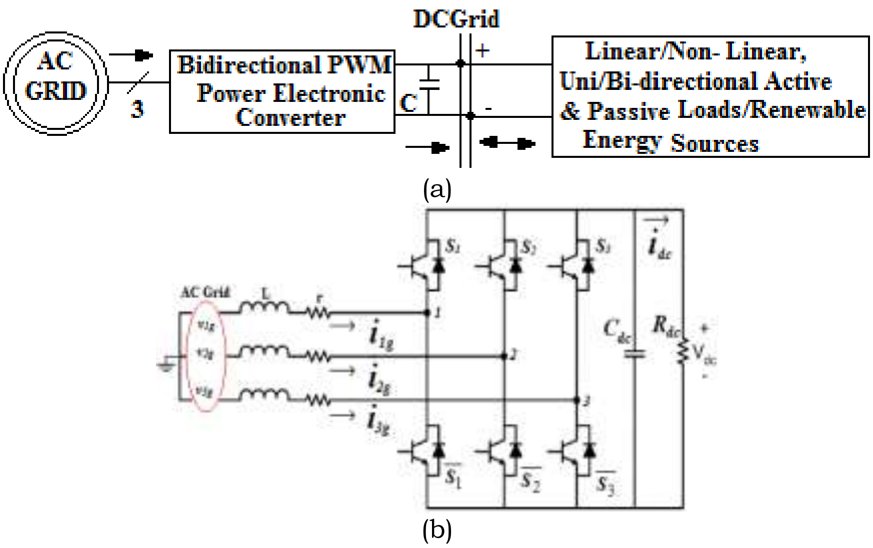



Fig.1 (a) Overall block diagram of power transfer between REHS, (b) Interfacing circuit diagram of three-phase PWM Boost rectifier

In this Tracking Controller based Predictive algorithm is designed to compute the predetermination of the Reference Current Templates (RCT). This RCT is actually followed by actual AC grid currents based on the prediction of the input and output error cost function, this cost minimization is reduced ripples in the actual AC grid currents for every switching period.

**Control Algorithm**

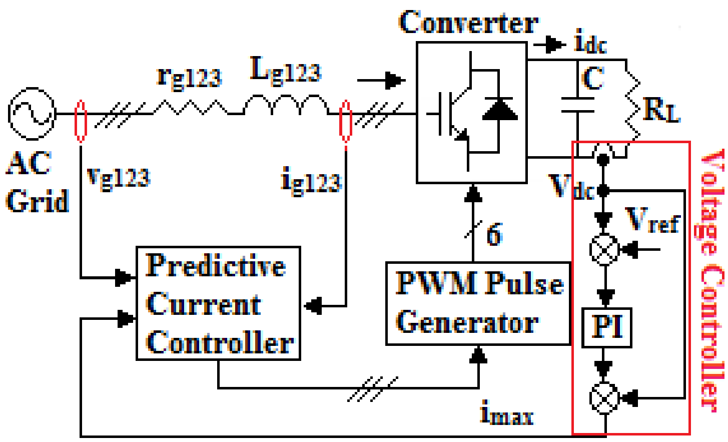



Fig.2 Overall control algorithm of the TCP based VSC

**Outer Loop Controller**

The above Fig represents the outer loop of the PI controller. The DC link voltage is regulated to the DC reference voltage using Proportional and Integral controller. The DC link voltage is compared with DC reference voltage $V_{ref}$ and the error is fed to the PI controller processed and it maintains constant DC voltage. The value of the $k_p$ and $k_i$ is found to be 3 and 0.3. The error is multiplied with actual DC link voltage is using to generate the RCT.

$$i_{max} = V_{dc}(V_{ref} - V_{dc})(K_p + \frac{K_i}{s}) \tag{4}$$

**Reference Current Generation using Tracking Controller based Predictive (TCP) Algorithm**

The next sampling of current templates are calculated using predict the previous of current templates. The RCT is generated using TCP algorithm using every sampling period, $T_s$ is given by as follows:

$$i_{g1}(k+1) = .i^*_{g1}(k+1)$$
$$i_{g2}(k+1) = .i^*_{g2}(k+1)$$
$$i_{g3}(k+1) = .i^*_{g3}(k+1) \tag{5}$$

In a balanced system of this proposed system, the voltage vector of the next sampling templates can be derived from the $v_{g1}$, $v_{g2}$, $v_{g3}$ of actual Grid voltage signals at the current time through rotation of the angle $\omega T_s$ as the following:

$$\begin{bmatrix} v_{g1}(k+1) \\ v_{g2}(k+1) \\ v_{g3}(k+1) \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta+120) & \cos(\theta-120) \\ \cos(\theta-120) & \cos\theta & \cos(\theta+120) \\ \cos(\theta+120) & \cos(\theta-120) & \cos\theta \end{bmatrix} \begin{bmatrix} v_{g1}) \\ v_{g2}) \\ v_{g3}) \end{bmatrix} \tag{6}$$

The predictive states of the currents are following the previous states of the voltage AC grid given as below:

$$\begin{aligned} i^*_{g1}(k+1) &= G.v_{g1}(k+1) \\ i^*_{g2}(k+1) &= G.v_{g2}(k+1) \\ i^*_{g2}(k+1) &= G.v_{g3}(k+1) \end{aligned} \tag{7}$$

The objectives cost function is minimized, using the input current vector is equal to the next sampling period of required predictive RCT follows the synchronization of the sampling period. The value of the G is replaced as will predict as below:

$$\begin{bmatrix} i^*_{g1}(k+1) \\ i^*_{g2}(k+1) \\ i^*_{g3}(k+1) \end{bmatrix} = \frac{\sqrt{3}}{2}\frac{i_{max}}{V_m} \begin{bmatrix} v_{g1}(k+1) \\ v_{g2}(k+1) \\ v_{g3}(k+1) \end{bmatrix} \tag{8}$$

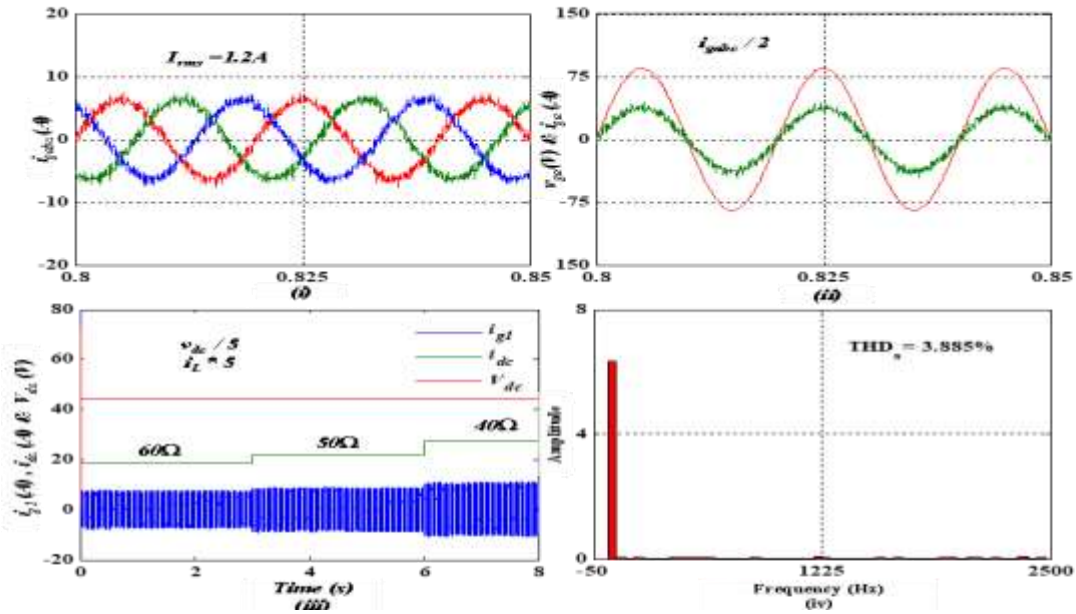
In this proposed TCP control algorithm, $T_s$ is assumed small for cost minimization of the predictive sampling period compare with the AC utility grid voltages, $v_{g1}$, $v_{g2}$, *and* $v_{g3}$ and also AC grid voltages are assumed constant at sampling period. The converter rectifier voltage is generated using TCP wit small switching, $T_s$ is as follows:

$$\begin{bmatrix} e_{g1}(k) \\ e_{g2}(k) \\ e_{g3}(k) \end{bmatrix} = \begin{bmatrix} v_{g1}(k) \\ v_{g2}(k) \\ v_{g3}(k) \end{bmatrix} - \frac{L}{T_s} \begin{bmatrix} i^*_{g1}(k+1) \\ i^*_{g2}(k+1) \\ i^*_{g3}(k+1) \end{bmatrix} + \frac{L}{T_s} \begin{bmatrix} i_{g1}(k) \\ i_{g2}(k) \\ i_{g3}(k) \end{bmatrix} \tag{9}$$

The required VSC of the average voltage vector to be generated during the switching period $T_s$, it is solved and achieved $e_{g1}(k)$, $e_{g2}(k)$ and $e_{g3}(k)$ are error of the predicting templates is feed to the PWM generator of the three-phase VSC.

**Simulation Results**

The proposed scheme of the TCP algorithm is verified through MATLAB/Simulink simulation using the following parameters are, $v_{g(1,2,3)}$ = 40V (RMS), $V_{ref}$ = 220V, f=50Hz, L= 1e-3H, C=3e-3F, $R_L$=40Ω, $K_p$=3, $K_i$=0.3. The DC grid voltage is selected as 220V. The AC grid voltages are utilized to convert to DC and its reference current templates are generated using TCP algorithm. The ode 45 solver is used for simulation and other parameters are maintained at default settings. The reference current templates are generated with voltage controller of the output. The reference current templates are compared with the actual current signals and fed to the PWM generator, this PWM generator of this system controls the output of the DC regulated voltage and input AC grid currents and it harmonics are very much reduced to the below 5%. The static and dynamic variations are simulated and represented. The DC output voltages are regulated from the minimum variations of the AC grid voltages. These AC grid voltages are can be possible to interface with Renewable Energy Sources (RES) like wind power generation plant. The Fig. 3(i) represents nearly sinusoidal AC grid actual current is achieved through TCP control algorithm, Fig. 3(ii) represents the unity power factor of the reactive power compensation of the AC grid voltage and current. Fig. 3(iii) dynamic variations of the proposed system of the VSC and DC current and voltage are varied depends upon the passive load with variations of the AC grid voltages. The output DC voltage are tracked to the given reference constant DC templates. The Fig. 3(iii-v) represents the harmonic spectrum of the input AC grid currents. This TCP based control algorithm very much reduced ripples in this AC current signals compared to other controller.



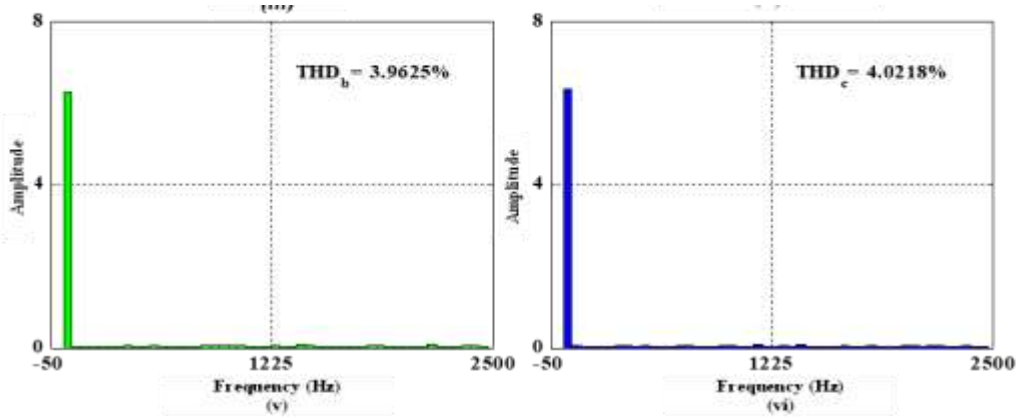



Fig.3 Simulation results of fixed wind speed with fixed PV voltage

(i) Compensated AC grid currents
(ii) Compensated grid current and grid voltage with UPF
(iii) Dynamic variations of the DC voltage
(iv-vi) Harmonic Spectrum of the AC grid currents

## Conclusions

The VSC's are very much vital roles in the power electronic industry due to bidirectional operations. The VSC can be interface with any other network. This paper explains about the new control algorithm of TCP (Tracking controller based Predictive) based control algorithm is proposed. This proposed algorithm used to achieve reactive power compensation and unity power factor. The outer PI filter is used for tracking of the DC output regulated voltage to the constant DC. It can also possible to interface with RES like wind and solar. This system is gives more advantages, because switching losses and other electromagnetic losses. The filter of the size also reduced and it acts as a inverter. This proposed system gives less ripples of the AC grid signals and output DC regulated voltage. Unity power factor also achieved in this system. It is easily interface to the PMSG like wind power system.

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