International Journal of Industrial Electronics, Control and Optimization © 2021 IECO
Vol. 4, No. 3, pp. 267-276, July (2021)

Robust Sliding Mode-based UPQC for Transient Conditions in Weak/ Islanded Networks

Omid Moradi[1], Saeed Abazari[2†],Nima Mahdian Dehkordi[3]

[1,2] Department of Engineering, Shahrekord University, Shahrekord, Iran
3 Department of Electrical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran

ABSTRACT

This paper proposes a nonlinear model by an optimal stabilizing controller for weak/islanded grids using a unified power quality conditioner (UPQC). The UPQC can be employed to stabilize a grid-tie inverter (GTI) or a synchronous generator (SG) with minimum control effort. The idea that GTI behavior is like synchronous generator is implemented in this study. The research aims at using advanced controller to reduce oscillations and achieve stability in a micro-grid. Here, the robust sliding mode controller-based UPFC is employed to design an optimal grid stabilizer. The paper considers variations in UPQC terminal voltage during the transient period of the system, unlike other articles that assume it to be constant. The performance of the proposed algorithm is evaluated by two benchmark networks. The paper presents a comparative study of transient stability in a micro-grid system under different loads. Simulation results reflect the robustness of the proposed sliding mode controller for oscillation reduction in comparison with the Lyapunov-based nonlinear optimal controller and PI controller. In addition, results show the effectiveness of the proposed nonlinear controller in controlling both GTI and SG in the micro-grid system.

Article Info

Keywords:
Micro-grid, Power system stability , Sliding Mode Controller (SMC), Virtual synchronous generator (VSG).

Article History:
Received 2020-10-02
Accepted 2020-12-20

I. INTRODUCTION

Recently, several researchers have paid significant attention to the problem of integrating renewable energy sources into power systems by similar characteristics of synchronous machines (SMs)[1]. The interaction between the power network and the corresponding micro-grid has been one of the most important issues in the electrical industry for the past few years. These networks face faults thataffect stability and protections [2].

The main difference between power networks and micro-grids is their energy-saving capabilities. Power networks have big power machines, and they have high potential for energy saving when a fault occurs, so they use this energy to achieve stability after clearing the error[3].However, in micro-grids, the energy-saving capability is very low so, these networks usually with fewer variations have most oscillations against. In micro-grids, renewable generators are usually applied, which connect to the network through a grid-tie inverter (GIT). By applying a proper controller method on DC links, the capacity of energy stability can be increased in a limited level. These phenomena have not been addressed in recent researches adequately.

For renewable generators (RG), the idea that GTI behavior is similar to a synchronous generator is implemented in many studies [4-9].Most studies in this field do not consider the capacitor stability and total stability of the system. In [4], the concepts of virtual synchronous machines (VSM) are presented. In this case, power electronic devices can produce virtual inertia that equals the rotor inertia of the synchronous generator. However, in this research, it is assumed that the inverter has unlimited energy. Moreover, the DC-link dynamic is not considered. In [5] and [7], the renewable source is connected to the main grid, and the inverter power is controlled. In this study, the inverter is modeled similar to an SG by considering a fictitious rotor angle, and the GTI phase angle mimics an SG rotor angle. In [10], an effective damping method to improve the VSM responses is proposed.

†**Corresponding Author**: abazari-s@eng.sku.ac.ir
Tel: +98-9133144539, University of Shahrekord, Faculty of Electrical and Computer Engineering, University of Shahrekord, Iran

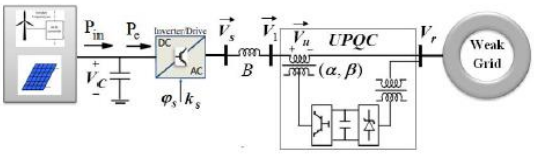


Fig. 1. RG connected to weak grid

But the DC-link voltage stability is not considered. In [11], a short-timeenergy reservoir is added to the network inverter and imaginary virtual inertia is obtained. This method eventually leads to the high cost of the combination compared to the DC-link capacitor. In [12], it is assumed that the capacitor dynamic is negligible, and small-signal analysis is used for the performance study of the islanding mode. This method extremely depends on DC-link with large capacity, and it is not practical in some cases. Also in applying rotating mass in virtual SG (VSG), the method needs the derivation of speed signal. In [13], a VSM control algorithm is proposed that simulates the traditional synchronous machine features. However, the synchronous machine inertia and the damping characteristics need to be changed, which makes the cost and simplicity of the operation economically important.

In all the above methods, SG-like behavior is assumed for flawless power systems. This assumption may not be correct in weak networks during fault occurrence. In stability discussion, the linear system theorem has been used for many years [14-15]. In most of these works, the nonlinear power grid model has been linearized around an operating point. However, these approaches assume that network variables are located in a small range of the reference operating point. In general, linear models of nonlinear systems are reliable only in specific regions, i.e., the operating point in which the system is linear. The model of a power network is nonlinear, especially during short circuits and transient behavior. Therefore, the linear system theorem is not applicable, and nonlinear controller designing is desirable for these systems.

The goal of optimal control in a power system is not only to maintain the system stability but also to reduce the speed of the oscillations with minimal effort to keep the desire performance. This case leads to the reduction of electrical stress on devices. Distributed flexible ac transmission systems (DIFACTS) elements are utilized to enhance control performance in distribution and micro-grid systems. This fact extends the control area to some broader stability. One of the most complete elements in micro-grid networks is UPQC. In distribution systems and micro-grids, UPQC can be equipped to increase network stability[16-17]. In addition to stability, these methods can improve power quality [18] and increases nonlinear loads [19]. In this paper, a robust sliding mode controller-based UPFC that uses intelligent algorithms is employed which can lead to a high degree of transient stability improvement. The typical characteristics of the SMC are that it is discontinuous and forces the system variables to slide along a pre-defined sliding surface to maintain stability. The controller is robust and can handle modeling inaccuracies.

This paper focuses on micro-grid and power network nonlinear features. Also, variations in terminal voltages are considered during the transient period, unlike previous works in which only a kind of single machine system connected to an infinite bus is used. Furthrmore, this idea that GTI behaviour is alike synchronous generator is implemented and the capacitor stability and total stability of the system is consider. A sliding mode controller (SMC) is presented to generator oscillation reduction. Further in order to better compare results, the Lyapunov controller and PI controller are designed.

This paper first describes the appropriate model of the renewable generator dynamics along with UPQC and the idea that the GTI behaves similar to the synchronous generator in Section II. The model is suitable for networks with renewable energy sources connected through GTI and the networks with SG. Next, Section III presents the system oscillation equation.Subsequently, Section IV discusses the design of a sliding mode controller to improve stability and reduce fluctuations after a fault. In general, the optimized proposed nonlinear controller is impressionable to operational changing conditions. It leads to the desired operation of the system even with topology or fault location changes. In Section V, in two benchmark networks, simulation results are proven for both low and high powers to consideration and optimization of the proposed optimal controller in comparison with a Lyapunov controller and a PI controller. Eventually, the paper is closed with some conclusions in Section VI.

II. DYNAMIC MODEL OF THE RENEWABLE GENERATOR WITH UPQC

This section presents the dynamic model of a renewable generator connected to the GTI along with UPQC shown in Fig. 1. The presented model applies for both RG and SG, so the proposed sliding mode controller (introduced later) can be used for both.

A. Renewable generator

where V_c is the dc link voltage of the renewable source, P_{in} is the power injected into the dc link by renewable energy sources, and P_e is the power delivered to the inverter. The electrical power P_e can be expressed as.

$$CV_C\dot{V}_C = P_{in} - P_e \quad (1)$$

Where C is the capacitance, V_c is the dc link voltage of the renewable source, P_{in} is the power injected into the dc link by renewable energy sources, and P_e is the power delivered to the inverter. The electrical power P_e can be expressed as

$$P_e = V_S V_1 B \sin(\phi_s - \theta_1) \quad (2)$$

where V_s is inverter output terminal voltage, $\varphi_s = \widehat{\varphi_s} + \varphi_{s0}$ is the inverter voltage phase angle, $\widehat{\varphi_s}$ and φ_{s0} are the phase steady- state and error values, respectively, and V_1 and θ_1 are the voltage and phase angle of the grid bus connected through B admittance, respectively. To regulation the RG output power, the phase angle of the GTI (φ_s) can be changed and thus acts like the rotor angle in a synchronous generator [20]. An auxiliary variable υ is used to control φ_s in a renewable generator and can be determined such that

$$\dot{\widehat{\varphi}}_s = \upsilon \quad (3)$$

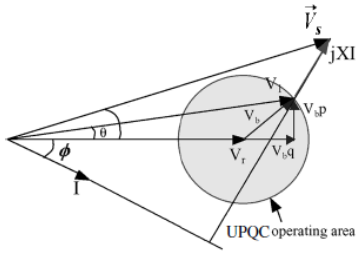


Fig. 2. Vector diagram of a UPQC connected to a network

The variable υ is similar to the rotor speed in a synchronous generator. In synchronous generators, speed is related to the kinetic stored energy in the rotor, and since the stored energy of the dc link capacitor can be changed by the GTI output power (via the output voltage phase error), it can be written as follows in order to create a significant relationship between υ and the energy stored in the dc link:

$$\dot{\upsilon} = V_C \dot{V}_C = (1/C) \times (P_{in} - P_e) \quad (4)$$

Here, saved energy is calculated based on the capacitor voltage V_C according to Eq. (1). Therefore, the inverter phase angle error $\widehat{\varphi_s}$ is determined as a new state variable besides the variable v which mentions the capacitor saved energy changing.

$$\upsilon = (V_C^{\,2} - V_{C0}^{\,2}) / 2 \quad (5)$$

Eq. (5) indicates the amount of change in the stored energy of the dc link with *Vco* as the steady-state value of V_C. In a renewable generator, capacitor *C* plays the role of inertia of the machine, which means that its higher size reduces oscillation and contributes to dynamic stability.

In the proposed *GTI* model, by controlling the phase angle and gain, the renewable generator is modeled like synchronous generator dynamic where dc-link capacitor acts as energy storage like the rotor of the synchronous generator. Unlike the current VSG models [4-8] where imaginary inertia is considered, energy reserved in the dc-link capacitor plays the role of kinetic energy storage and appears as a dynamic state.

In the proposed method, GTI can be controlled with a simulation mechanism like an automatic voltage regulator (AVR) and a power system stabilizer (PSS) and their equivalent nonlinear features. Here, the equivalent classical-model SG, $M = C/\tau$ is inertia, $\delta = \varphi_S$ is rotor angle and $\omega = \upsilon$ is rotor speed error (capacitor voltage indicator) [2]. Therefore, the dc-link capacitor dynamic in Eq. (4) is taken into account like the rotor dynamic in the classic model of the generator. For the proposed model, there is no storage device or enormous capacitor capacity, and energy is provided by a usual dc-link capacitor.

B.UPQC Modelling

A simplified scheme of a UPFC connected to the grid is shown in Fig. 1. UPQC includes a series transformer with X_{SR} reactance, a shunt transformer with X_{SH} reactance, two three-phase voltage source converters, and one dc-capacitor link. C_{dc} and v_{dc} are capacitance and dc-link voltage, respectively. According to the single-line diagram shown in Fig. 1, the UPQC vector diagram connected to the network is shown in Fig. 2 [22].

According to Fig. 2, *Vbp* and *Vbq* are the components of the series voltage of UPFC and can be written as

$$V_{bq} = V_r \beta(t) \quad and \quad V_{bp} = V_r \gamma(t) \quad (6)$$

where $\beta(t)$ and $\gamma(t)$ are converter gains for generating voltage $\vec{V}_u$ in UPQC series transformer. Neglecting network losses, according to Eq. (2), the electrical power can be expressed as

$$P_e = V_S V_1 B \sin(\delta - \theta_1) = V_S V_1 B (\sin\delta\cos\theta_1 - \cos\delta\sin\theta_1) \quad (7)$$

According to Fig. 2, it can be shown that $\cos\theta = (V_r + V_{bq})/V_1$ and $\sin\theta = V_{bp}/V_1$. As a result, according to Eq. (4), it can be used to obtain

$$\dot{\omega} = \left(\frac{1}{C}\right)\left(P_{in} - V_S V_r B \sin(\delta) + V_S B \cos(\delta) V_{bp} - V_S B \sin(\delta) V_{bq}\right) \quad (8)$$

In this paper, variations in terminal voltage V_r are considered during the transient period of the system, unlike [23] that assumes V_r to be constant. Therefore, the shunt terminal voltage can be decomposed into two fixed components $\bar{V}_r$ (steady-state value) and the variable part D (disturbance) such that $V_r = \bar{V}_r + D$. Thus, Eq. (8) can be rewritten as

$$\begin{aligned}\dot{\omega} &= \left(\frac{1}{C}\right)(P_{in} - V_S V_r B \sin(\delta)) \\ &+ \left(\frac{1}{C}\right)(V_S B \cos(\delta) V_{bp} - V_S B \sin(\delta) V_{bq}) \\ &- \left(\frac{1}{C}\right)(V_S B \sin(\delta)) D\end{aligned} \quad (9)$$

III. SYSTEM OSCILLATION EQUATIONS

The dynamic behavior of the system, as shown in Fig. 1, can be described by the swing equation as

$$\begin{cases}\dot{\delta} = \omega \\ \dot{\omega} = \hat{f} + \Delta f + \left(\frac{1}{M} P_{1u} - \frac{1}{M} P_{2u}\right)\end{cases} \quad (10)$$

Where ω is the relative rotor speed and δ is the relative rotor angle similar toasynchronous generator, defined as $\delta = \delta - \delta_0$ and $\omega = \omega - \omega_0$, respectively. Also, function $\hat{f}$, disturbance part Δf, and the powers P_{1u} and P_{2u} delivered to the system by UPQC are given by

$$\hat{f} = \left(\frac{1}{M}\right)\left(P_{in} - V_S V_r B \sin(\delta)\right)$$

$$\Delta f = \left(-\frac{1}{M}\right)\left(V_S B \sin(\delta)\right) D$$

$$P_{1u} = V_S B V_{bp} \cos(\delta)$$

$$P_{2u} = V_S B V_{bq} \sin(\delta)$$

Note that since the reactance of the transmission line is much greater than its resistance, the value of the resistance is assumed to be zero in all calculations. This can simplify the equations without having a significant effect on the transient response. In the above system, under a steady state, the relative speed ω is zero and the angle δ remains unchanged. In the event of an error, the structure of the system changes and accelerates or decelerates the rotor speed of the generators, leading to power oscillations. In this case, power oscillations must be controlled very quickly for transient stability to occur. Sliding mode controllers can quickly and continuously adjust the reactive power to amplify the system damping by rapidly changing the UPQC impedance or equivalent by adjusting the line voltage at the UPQC location.

IV. Design of Local Sliding Mode Controller

SMC is a robust control approach appropriate for the control of time-variant systems in the presence of external disturbances. SMC uses a high-speed switched feedback control to sustain the control variable on the sliding surface. The gain in the feedback path switches between two values according to a rule that depends on the value of the variable at each instant. The aim is to drive the plant's state trajectory onto a pre-specified surface in the state space and to maintain it on this surface for subsequent time. A Lyapunov approach is used to characterize the switched control design that will maintain the plant state on the surface after interception [24].

The design procedure involves two steps: the selection of a sliding surface and the computation of a control law to force the system's trajectory towards and keeping it on the sliding surface. Consider the second-order system

$$\ddot{x} = f(x) + g(x)u \tag{11}$$

Where u is the control input, x is the state vector, and the dynamics f (possibly nonlinear or time-varying) is not exactly known but estimated as $\hat{f}$ .We have state equations by

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f(x) + g(x)u \end{cases} \tag{12}$$

The estimation error of f is assumed to be bounded by some known function $F = F(x, \dot{x})$;

$$\left|f - \hat{f}\right| \le F \tag{13}$$

Let $e = x_d - x$ be the tracking error in the variablex. Furthermore, let us define a surface S in the state-space R(2) by

$$S = \dot{e} + \lambda e \tag{14}$$

and λ is a strictly positive constant. Differentiation of the sliding variable gives

$$\dot{S} = \ddot{x}_d - \ddot{x} + \lambda(\dot{x}_d - \dot{x}) \tag{15}$$

This implies that

$$\dot{S} = \ddot{x}_d - \hat{f} - \Delta f - g(x)u + \lambda\dot{e} \tag{16}$$

The simplified, l St-order problem of keeping the scalar S at zero can now be achieved by choosing the control law u of Eq.(1) such that outside of S. This control law was formulated by the use of the Lyapunov stability theorem.

$$\frac{1}{2}\frac{d}{dt}s^2 \le -\eta|s| \;\Rightarrow\; \dot{s}\,\mathrm{sgn}(s) \le -\eta \tag{17}$$

where η is a strictly positive constant. We then have

$$(\ddot{x}_d - \hat{f} - \Delta f - g(x)u + \lambda\dot{e})\,\mathrm{sgn}(s) \le -\eta \tag{18}$$

The best of a control law that would achieve $\dot{s} = 0$ is thus

$$g(x)u = \ddot{x}_d - \hat{f} + \lambda\dot{e} \tag{19}$$

In order to satisfy sliding condition (17) despite uncertainty on the dynamics f, we add to Eq. (19) a term discontinuous across the surface s=0, so

$$g(x)u = \ddot{x}_d - \hat{f} + \lambda\dot{e} + k\,\mathrm{sgn}(s) \tag{20}$$

By choosing k to be large enough, we can now guarantee that Eq. (17) is verified. Indeed, we have from Eq. (18) and (20)

$$k + \Delta f\,\mathrm{sgn}(s) \ge \eta \tag{21}$$

So that, letting

$$k = F + \eta \tag{22}$$

Here F is a known bound for error estimation. If g(x) is known, the control law from Eq. (20) is as follows

$$u = \frac{1}{g(x)}\left(\ddot{x}_d - \hat{f} + \lambda\dot{e} + (F+\eta)\mathrm{sgn}(s)\right), g(x) \ne 0 \tag{23}$$

If $g_{\min} < |g(x)| < g_{\max}$ we have

$$u = \frac{\left(\ddot{x}_d - \hat{f} + \lambda\dot{e} + (F+\eta)\mathrm{sgn}(s)\right)}{g_{\min}}\mathrm{sgn}(g) \tag{24}$$

A higher value of k essentially compensates for a larger uncertainty, and results in better tracking.

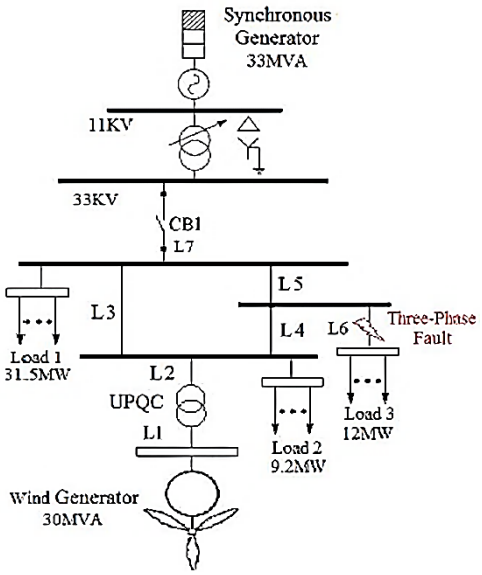


Fig. 3. Wind farm connected to the weak network [25].

However, this benefit comes at the expense of an undesirable higher control activity (chattering) around the sliding surface. A typical solution in this paper is to replace the discontinuous *signum* function, in *sgn(s)* in Eq. (20), by the smoother function sat(x/ φ), where φ >0. With such modification all control signals would be continuous with no high-frequency (chattering) activities.

In this paper, the PSO algorithm is applied to approximate the unknown coefficients required in the controller.

V. Simulation Results

In this section, the realization of stability through simulation to illustrate the effectiveness of the sliding mode controller in reducing the power oscillations on weak and islanded grids using UPQC is presented by implementing two scenarios. The two scenarios are implemented in a similar way to [25].

A. Case Study1

In this section, controller performance is considered in oscillation damping for a wind farm connected to a small power grid [26] through a GTI according to Fig. 3. As previously mentioned, all available excitation control methods for the simultaneous generator can be used for a renewable generator equipped with a proposed mechanism such as GTI excitation. The PSO algorithm is applied to approximate the unknown coefficients required in the controller. Further, to enhance the performance of the UPFC, PSO-based SMC, Lyapunov controller, and PI controller [27] are designed to improve the damping of oscillations and transient stability of the system. Transient responses of the three controllers are compared in RG dc-link voltage, SG speed, series voltage, and injected power of UPQC. The network is simulated using Table I data in Matlab software.

TABLE I

Microgrid Parameters for High Power Scenario [25].

Generator Characteristic	Base Power	33MVA
	Base Voltage	11KV
	x_d	0.264pu
	$H = \omega_s M / 2$	1.3S
Load	Load 1	31.5 MW(PF=0.98)
	Load 2	9.2MW(PF=0.98)
	Load 3	12MW(PF=1)
Line	Resistance(R)	$0.02546\,\Omega/km$
	Inductance(L)	$0.9337\,mH/km$
	Capacitance(C)	$0.0127\,\mu F/km$
	Total Length of grid=5km	
Renewable Sources	Power	21.6MW

TABLE II

Microgrid Parameters for Low Power [25].

Scenario Load	Load 1	15.75Mw(pf=0.98)
	Load 2	4.6MW(PF=0.98)
	Load 3	6MW(PF=1)
Renewable Sources	Power	18MW

Speed governor and PSS are applied to the SG in all simulations. To prove the robustness of the controllers, the analysis is tested under different loads according to Tables I and II. As is seen in Fig. 3, a three-phase fault occurs in one of the lines. To run the simulation, at first, there is no fault in simulation for 0.2s, and a fault is then imposed for 50ms. The controller does not inter during the fault to prevent the exorbitance series voltage injection. In fact, the controller will inter after fault clearing. The process has robustness and satisfactory performance in a wide range. Figs. 4 and 5 show the ability of the proposed controller (SMC) to improve the system oscillations in high power scenarios.

Fig. 4a shows the RG dc-link voltage and Fig. 4b shows the SG speed according to which system oscillations are considerable after fault occurrence and the system tends to instability. Then, using the UPQC with the proposed controllers, the oscillations are greatly reduced. As shown in Figs. 4c and 5, the UPQC series voltage and power into the transmission line using the optimal proposed controller (SMC) are in acceptable ranges where the maximum UPQC power is around 1.1 MW that is about 4% of the transmission line power. In the proposed method, the robustness of the optimal controller is provable with the execution of the second scenario under a low load level according to Table II. According to Fig. 6, it is observed from the transient response of the microgrid system that the oscillations are minimized because of the proposed controllers and are subsequently died out with minimum settling time and overshoots. Also, the simulation shows the satisfactory damping performance of the proposed SMC controller verifying the robustness of the optimal controller working at different loads.

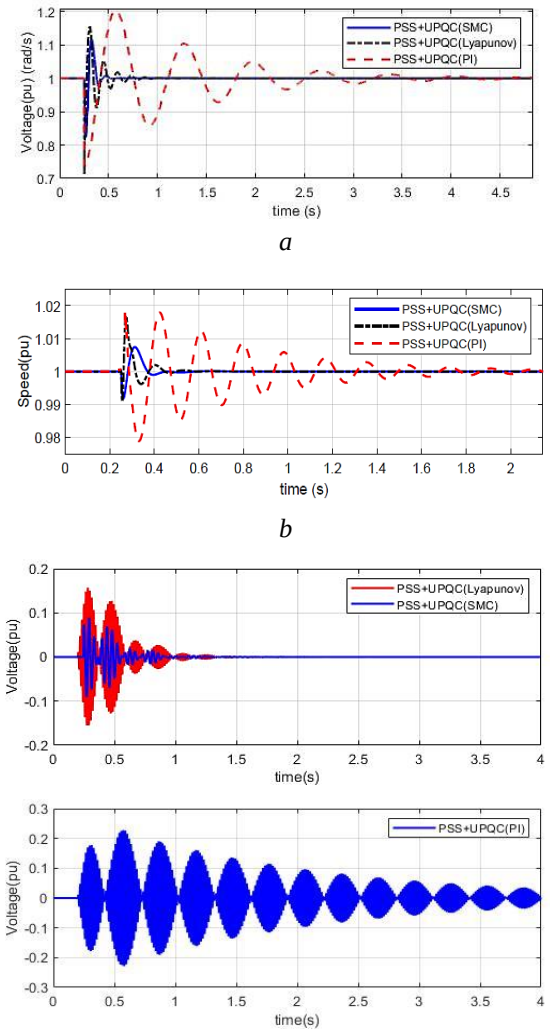


Fig. 4. Case study 1- high load levels: comparison of the proposed optimal nonlinear controller by SMC, Lyapunov controller and PI controller

a:RG dc-link voltage, b: SG speed, c: UPQC series voltage

B. Case Study2

In the second simulation scenario, the damping of power system oscillations is investigated by comparing the performance of the proposed optimal controller with the Lyapunov controller and PI controller. Here, the effectiveness of the proposed controllers in the islanded microgrid is studied in which oscillations in SG are controlled by UPQC. As shown in Fig. 7, the microgrid contains SG, renewables source, and loads. Table III shows the specifications of the test system.

Here, the proposed nonlinear optimal controller and two other controllers are applied to the UPQC series transformer to improve the transient characteristics. In all simulations, the speed governor and PSS are active. According to Table III, the loads are constant impedance with a power factor of 1 and 0.9.

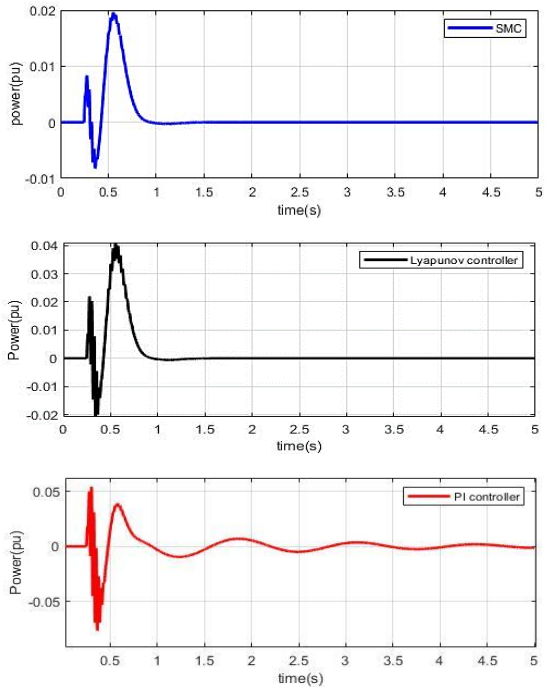


Fig. 5. Case study 1- high load levels: Injected power of UPQC comparison of the proposed optimal nonlinear controller by SMC, Lyapunov controller and PI controller.

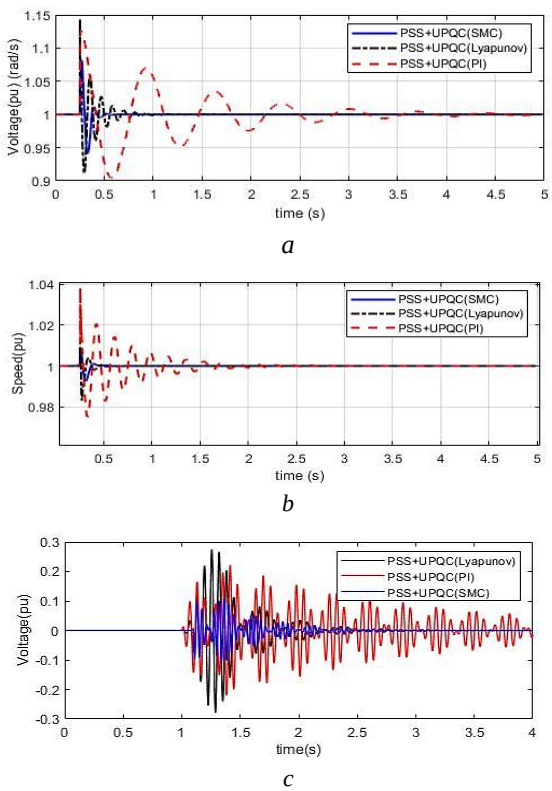


Fig. 6.Case study 1- low load levels: comparison of the proposed optimal nonlinear controller by SMC, Lyapunov controller and PI controller

a:RG dc-link voltage, b: SG speed, c: UPQC series voltage

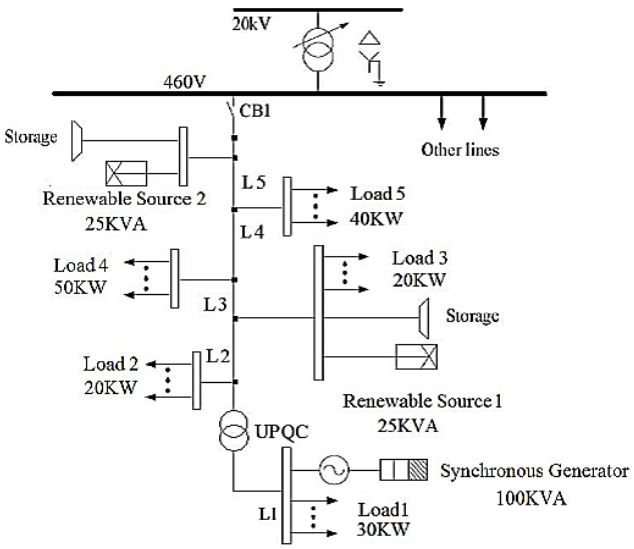


Fig.7 . Benchmark low-voltage microgrid [25].

TABLE III

Grid Parameters with High Load Levels [25].

Generator Characteristic	Base Power	100 KVA
	Base Voltage	460 V
	x_d	0.17 pu
	$H = \omega_s M / 2$	0.1268 S
load	Load 1	30KW(PF=1)
	Load 2	20 KW(PF=1)
	Load 3	20 MW(PF=0.9)
	Load 4	50 KW(PF=1)
	Load 5	40 KW(PF=0.9)
Line	Resistance(R)	$0.02546\,\Omega / km$
	Inductance(L)	$0.9337\,mH / km$
	Capacitance(C)	$0.0127\,\mu F / km$
	Total Length of grid=5km	
Renewable Sources	Power	30 KW

Renewable energy sources have been used to transfer fixed power to the grid. These sources are connected to the network via impedance. Here, to help reduce sudden energy fluctuations, renewable energy sources are equipped with storages, unlike the previous scenario. A three-phase fault occurs in the UPQC bus.

To perform the simulation, the system is first simulated for 1 second without any faults; then, a three-phase fault is applied for 100ms. The controller acts after fault removal (t=1.1s). Figs. 8 and 9 show the damping effect of the UPQC controller by the proposed algorithm with the SMC method compared to the Lyapunov and PI controller in the presence of PSS and governor.

The SG speed in Fig. 8a is shown, according to which the proposed nonlinear optimal controller can reduce post-fault oscillations with less amplitude and time compared to the figure 8band 8c Lyapunov and PI controller. The UPQC series voltages in Fig. 8 and the power injected UPQC to the line are shown in Fig. 9. According to Figs. 8b and 9, the injected series voltage is less than 0.1PU, and the maximum power injected by UPQC is about 0.28 of the line power and about 1.5 kW. It is clearly evident that the proposed controller has a better transient response and the voltage and power injected by the UPQC series transformer are lower than those of the Lyapunov and PI controller.

Next, the error time is increased to 0.2s and the performance of the SMC with the Lyapunov and PI controller are compared. It is notable that the speed of response and the settling time are improved using SMC in comparison with the Lyapunov and PI controller.

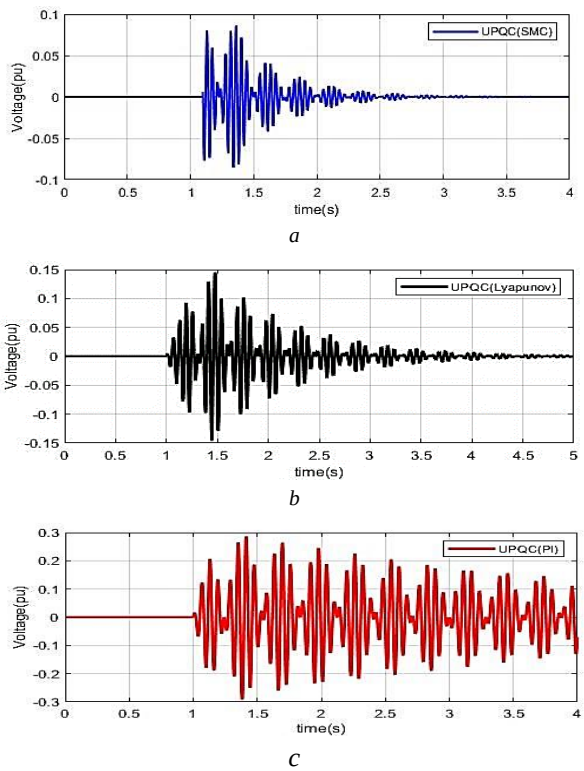


Fig. 8. Case study 2 -Comparison of the proposed optimal a:nonlinear controller (SMC), b:Lyapunov controller c: PI controller; fault duration 0.1 s.
a:SG speed, b: UPQC series voltage

Due to changing conditions after the network error, as shown in Figs. 10 and 11, the performance of the PI controller is different from the performance of the SMC and Lyapunov controller. This is due to the fact that the linear models of the nonlinear systems are reliable only in specific regions, i.e., the operating point, in which the system is linear [28]. It is clear that the PI controller, even with more effort to control, cannot reduce the oscillations to the size of the proposed controller.

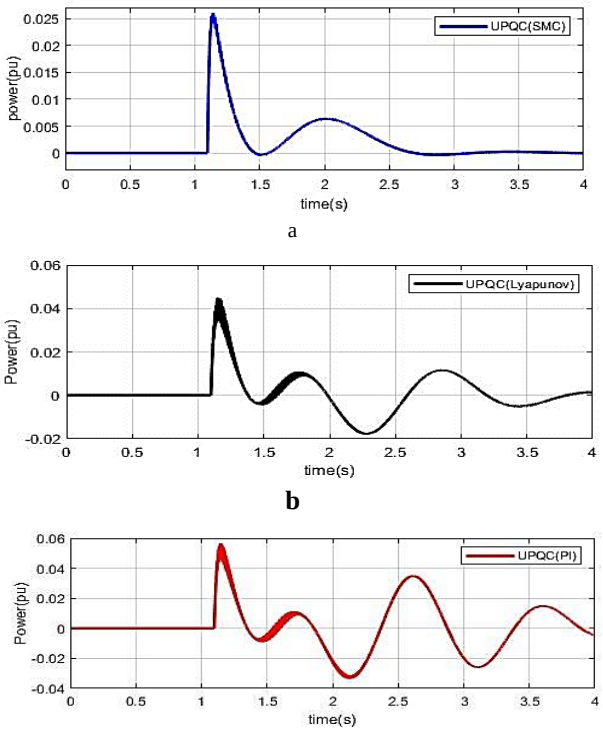
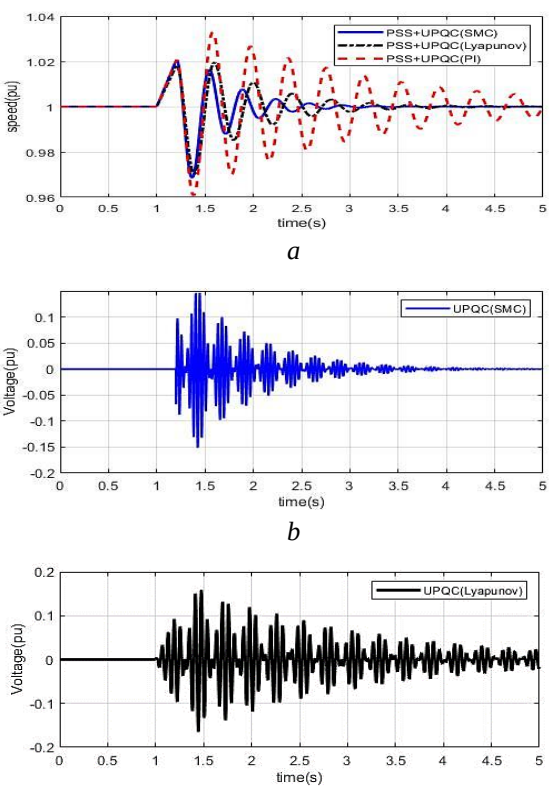


Fig. 9. Case study 2- Comparison of the proposed optimal a:nonlinear controller (SMC), b:Lyapunov controller c: PI controller - Injected power of UPQC; fault duration 0.1s.



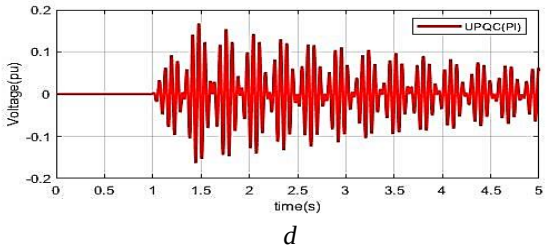


Fig. 10. a:Case study 2 -Comparison of the proposed optimal nonlinear controller (SMC), Lyapunov controller and PI controller; fault duration 0.2 s.
b: UPQC series voltage(SMC)c: UPQC series voltage(Lyapanov) d: UPQC series voltage(PI)

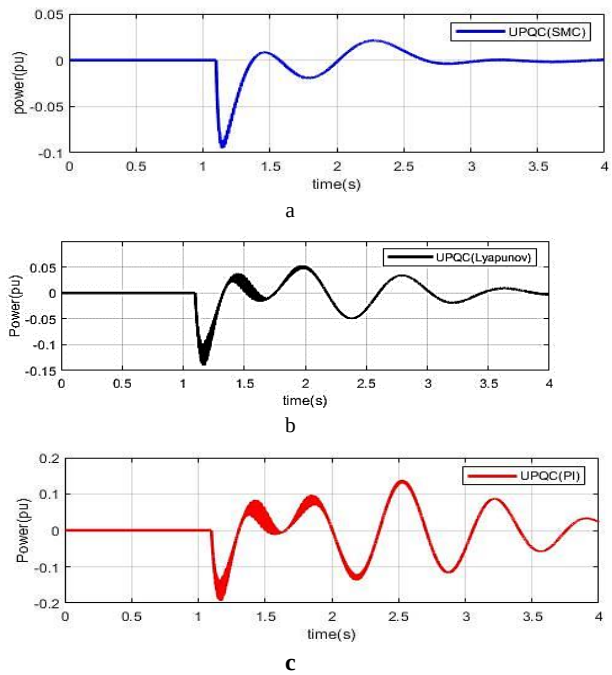


Fig. 11. Case study 2- a:Comparison of the proposed optimal nonlinear (SMC)b: Lyapunov controller c: PI controller- Injected power of UPQC; fault duration 0.2 s.

VI. Conclusion

In this paper, a nonlinear optimal controller is used to reduce oscillations in a renewable energy source and in the synchronous generator connected to the weak grid and microgrid. Using the new modeling approach, a network equipped with UPQC is modeled as a nonlinear dynamic system. In addition to its power quality tasks, UPQC acts as a motive controller by series voltage injection. In this study, a dynamic model of the network with a third rank model of SG and UPQC as a stabilizer element is used. After standard form determination, a sliding mode controller (SMC) is presented to generator oscillation reduction. To optimize the controller

parameters, a PSO algorithm is presented according to the new acceleration coefficient. The method is practicable without complicated calculations and makes a good balance between the general and local search of the main algorithm. The results show that the proposed algorithm achieves an exact solution for all problems. In this paper, the realization of stability through simulation to illustrate the effectiveness of the sliding mode controller in reducing the power oscillations on weak and islanded grids using UPQC by implementing two scenarios is proven. Further, to better compare the results, the Lyapunov controller and PI controller are designed. According to the simulation results, the proposed algorithm has a considerable impact on oscillation reduction. Also, it is sustained against variations of load and error time. Robustness against parameters' variations and disturbance rejection properties are two important capabilities of the proposed SMC. Besides, these two properties are the main weaknesses of the linear controllers and cannot be ignored in practical applications because high order dynamics, measurement errors, modeling errors, and the nonlinear nature of power systems are inevitable.

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Omid Moradi received his B.Sc. degree in electrical engineering from Islamic Azad University, Khomienishahr, Iran, in 2005, the M.Sc. degreein electrical engineering from Sajad University of Technology, Mashad, Iran, in 2007,. He joined the the Department of Electrical Engineering, Jahad Daneshgahi higher Education Institute, Isfahan, Iran, in 2009, where he is currently an Instructor. He admitted to Shahrekord University in 2014 as a Ph. D student .His research interests include power systems, control systems, nonlinear control, controlledof FACTS elements in power and microgrid systems.



Saeed Abazari received his B.Sc. degree in electrical engineering from Isfahan University of Technology, Isfahan, Iran, in 1989, the M.Sc. degree from Ferdowsi University, Mashhad, Iran, in 1992 and the Ph.D. degree from Sharif University of Technology, Tehran, Iran, in 2002. Currently, He is a Professor of the Electrical Engineering Department at the Shahrekord University, Shahrekord, Iran. His research interests are electric power distribution system, smart grid, power system operation and control and FACTS controllers.



Nima Mahdian Dehkordi received the M.Sc. and Ph.D. degrees from Sharif University of Technology, Tehran, Iran, in 2012 and 2016, respectively, both in electrical engineering. He joined the the Department Shahid Rajaee Teacher Training University Tehran, Iran, in2017, where he is currently an Assistant Professor. His research interests include control systems, applications of control theory in power electronics, microgrid control, distributed and cooperative control, internet of things, nonlinear control, and network control.