Robust Power System Controllers based on Differential Geometric Tools

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Abstract—**In this paper, a comprehensive and robust multi-variable nonlinear controller has been designed to achieve transient stability enhancement in multi-machine power systems. The proposed method effectively decentralizes the feedback controllers and hence, requires only local feedback variables being independent of the operating condition. Results are exhibited on a 39-buses 10-machines power system, when it is subjected to perturbations under different operating conditions.**

Index Terms*— *Nonlinear control, Power oscillations, Power system control, Transient stability.

I. Introduction

ELECTRIC power systems are physically some of the largest and most complex nonlinear systems in the world. Their nonlinear behaviors are difficult to analyze and predict due to several factors such as (*i*) the extraordinary size of the systems, (*ii*) the nonlinearity in the components and control devices, (*iii*) the dynamical interactions within the systems, (*iv*) uncertainty in the load behaviors, (*v*) complexity and different timescale of power system components (equipments and control devices). These complicating factors have forced to power system engineers to analyze power systems through extensive computer simulations.

Power systems are increasingly called upon to operate transmission lines at high transmission levels for economic and environmental reasons. This requires the control system to have the corresponding ability to suppress the potential instability and poorly damped power angle oscillations that might threaten the system stability as the load is expected to increase in the future [1, 2].

This paper deals with the problem of robust decentralized control of multimachine electric power systems. These systems are subjected to different perturbations, such as short circuits, connection and/or disconnection of loads, lines, or generators, etc. Then, the utilization of controllers which guarantee robustness under those perturbations to provide electrical energy to the loads with admissible stability margins is desirable. Likewise, controllers must be robust under parametric variations due to model uncertainties. Electrical power systems represent complex great scale nonlinear systems. Then, the controller design is a challenging problem.

The decentralized controllers are able to overcome such difficulties. The proposed controllers are based on a tracking problem, where the voltage and the speed reference values are employed as inputs; they can be implemented in any electric power system Results are exhibited on an equivalent of the Mexican high voltage grid.

The paper is organized as follows: (*i*) section II develops the power system formulation; (*ii*) section III presents the theoretical basis of the followed strategy; (*iii*) section IV illustrates results on a 10-machines power system; (*iv*) finally, conclusions are exposed.

II. Power System Formulation

Assume a power system constituted by n machines and m loads, connected through lossless transmission lines, where each generator is represented by an internal and a terminal voltage [3-5]. Let the n-*th* machine be the reference bus. One-axis model for each generator and active/reactive power demand is adopted [3-5]. The nonlinear differential algebraic equations are given by (1)-(2), with generator buses $i = 1, 2, \ldots, n$, and load buses $k = n+1, n+2, \ldots, n+m$. Algebraic constraints arise from the load flow equations on each generation and load bus.

$$\begin{bmatrix} \dot{\delta}_i \\ \dot{\omega}_i \\ \dot{E}'_{q_i} \end{bmatrix} = \begin{bmatrix} \omega_0 \left(\omega_i - 1 \right) \\ \dfrac{-D_i}{M_i} \left(\omega_i - 1 \right) - \dfrac{1}{M_i} P_{e_i} \\ \phi_i \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \dfrac{1}{M_i} & 0 \\ 0 & \dfrac{1}{T'_{d0_i}} \end{bmatrix} \begin{bmatrix} P_{m_i} \\ E_{f_i} \end{bmatrix} \qquad (1)$$

$$\vec{0}=\begin{bmatrix} \frac{E'_{q_i}V_i sen(\theta_i-\delta_i)}{X'_{d_i}}+\sum_{\substack{j=1\\ j\neq i}}^{n} B_{ij}V_iV_j sen(\theta_i-\theta_j)+\ldots \\ \sum_{k=n+1}^{n+m} B_{ik}V_iV_k sen(\theta_i-\gamma_k) \\ \frac{V_i^2}{X'_{d_i}}-\frac{E'_{q_i}V_i\cos(\theta_i-\delta_i)}{X'_{d_i}}-B_{ii}V_i^2-\sum_{\substack{j=1\\ j\neq i}}^{n} B_{ij}V_iV_j\cos(\theta_i-\theta_j)-\ldots \\ \sum_{k=n+1}^{n+m} B_{ik}V_iV_k\cos(\theta_i-\gamma_k) \\ -P_{d_k}+\sum_{i=1}^{n} B_{ki}V_kV_i sen(\gamma_k-\theta_i)+\sum_{\substack{l=1\\ l\neq k}}^{n+m} B_{kl}V_kV_l sen(\gamma_k-\gamma_l) \\ -Q_{d_k}-B_{kk}V_k^2-\sum_{i=1}^{n} B_{ki}V_kV_i\cos(\gamma_k-\theta_i)-\sum_{\substack{l=1\\ l\neq k}}^{n+m} B_{kl}V_kV_l sen(\gamma_k-\gamma_l) \end{bmatrix}$$

... (2)

where: $\delta=(\delta_1,\ldots,\delta_n)^T$ represents the internal voltage's angles; $\omega=(\omega_1,\ldots,\omega_n)^T$ represents the angular velocities; $E'_q=(E'_{q_1},\ldots,E'_{q_n})^T$ is the internal voltage's vector; $\theta=(\theta_1,\ldots,\theta_n)^T$ is the terminal voltage's angles; $V=(V_1,\ldots,V_n,V_{n+1},\ldots,V_{n+m})^T$ is the terminal and load voltage's vector; $\gamma=(\gamma_{n+2},\ldots,\gamma_{n+m})^T$ is the load angle's vector; B_{ij} is the ij-*th* element of the admittance matrix Ybus.

It is noteworthy that (1)-(2) exhibit the structure of a conventional state space formulation,

$$\begin{cases}\dot{x}=f(x,z)+g(x,z)u\\ 0=\sigma(x,z)\end{cases} \tag{3}$$

where x are the state variables and z the algebraic variables; $x=[x_1,x_2,\ldots,x_n]^T$, $x_i=[\delta_i,\omega_i,E'_{q_i}]^T$;

$z=[z_{g_1},z_{g_2},\ldots,z_{g_n},z_{l_{n+1}},z_{l_{n+2}},\ldots,z_{l_{n+m}}]^T$, $z_{g_i}=[\theta_i,V_i]^T$, $z_{l_k}=[\gamma_k,V_k]^T$;

$f=[f_1,f_2,\ldots,f_n]^T$,

$$f_i=\left[\omega_0(\omega_i-1),\left(-\frac{D_i}{M_i}\right)(\omega_i-1)-\left(\frac{1}{M_i}\right)P_{e_i},\phi_i\right]^T$$

$u_i=[P_{m_i},E_{f_i}]^T$;

$\phi_i=\frac{x_{di}}{x'_{di}T'_{d0i}}E'_{qi}+\frac{x_{di}-x'_{di}}{x'_{di}T'_{d0i}}V_i\cos(\delta_i-\theta_i)$; $g=diag[g_1,\ldots,g_n]$,

$$g_i=\begin{bmatrix}0 & 0\\ \frac{1}{M_i} & 0\\ 0 & \frac{1}{T'_{do_i}}\end{bmatrix}$$

Let *H(x,z)* be a continuous function such that system (1)-(2) be expressed by (4),

$$\begin{cases}\dot{x}=T(x,z)\nabla_x H(x,z)+g(x,z)u\\ 0=\nabla_z H(x,z)\end{cases} \tag{4}$$

where $T(x,z)=J(x,z)-R(x,z)$ is a structure matrix, with *J(x,z)* skew-symmetric and *R(x,z)* positive semi-definite. According to the Dissipative Hamilton Realization definition, function *H(x,z)* must satisfy constraints (5) along the system trajectories,

$$\begin{aligned} f(x,z)&=T(x,z)\frac{\partial H(x,z)}{\partial x}\\ 0&=\frac{\partial H(x,z)}{\partial z}\end{aligned} \tag{5}$$

Let $v_i=\ln(V_i)$ and $v_k=\ln(V_k)$ [3-5], then the algebraic power flow equations (2) become,

$$\vec{0}=\begin{bmatrix} \frac{E'_{q_i}e^{v_i} sen(\theta_i-\delta_i)}{X'_{d_i}}+\sum_{\substack{j=1\\ j\neq i}}^{n} B_{ij}e^{v_i+v_j} sen(\theta_i-\theta_j)+\ldots \\ \sum_{k=n+1}^{n+m} B_{ik}e^{v_i+v_k} sen(\theta_i-\gamma_k) \\ \frac{e^{2v_i}}{X'_{d_i}}-\frac{E'_{q_i}e^{v_i}\cos(\theta_i-\delta_i)}{X'_{d_i}}-B_{ii}e^{2v_i}-\sum_{\substack{j=1\\ j\neq i}}^{n} B_{ij}e^{v_i+v_j}\cos(\theta_i-\theta_j)+\ldots \\ \sum_{k=n+1}^{n+m} B_{ik}e^{v_i+v_k}\cos(\theta_i-\gamma_k) \\ -P_{d_k}+\sum_{i=1}^{n} B_{ki}e^{v_k+v_i} sen(\gamma_k-\theta_i)+\sum_{\substack{l=n+1\\ l\neq k}}^{n+m} B_{kl}e^{v_k+v_l} sen(\gamma_k-\gamma_l) \\ -Q_{d_k}-B_{kk}e^{2v_k}-\sum_{i=1}^{n} B_{ki}e^{v_k+v_i}\cos(\gamma_k-\theta_i)-\sum_{\substack{l=n+1\\ l\neq k}}^{n+m} B_{kl}e^{v_k+v_l}\cos(\gamma_k-\gamma_l) \end{bmatrix}$$

... (6)

Therefore, the new algebraic variables become $z_{g_i}=[\theta_i,v_i]^T$, $z_{l_k}=[\gamma_k,v_k]^T$. A function *H(x,z)* that holds the constraints (5) for the transformed system is

$$H(x,z)=E_k+E_p \tag{7}$$

where E_k (kinetic energy) and E_p (potential energy) are defined by [1]

$$E_k = \frac{1}{2}\sum_{i=1}^{n}\omega_0 M_i\left(\omega_i - 1\right)$$

$$E_p = \frac{1}{2}\sum_{i=1}^{n}e^{2v_i}\left(\frac{1}{X_{d_i}^{'}} - B_{ii}\right) - \frac{1}{2}\sum_{k=n+1}^{n+m}B_{kk}e^{2v_k} - \sum_{k=n+1}^{n+m}P_{d_k}\gamma_k + ...$$

$$Q_{d_k}v_k - \sum_{i=1}^{n}\frac{E_{q_i}^{'}e^{v_i}\cos\left(\theta_i - \delta_i\right)}{X_{d_i}^{'}} \quad (8)$$

$$-\sum_{i=1}^{n}\frac{X_{d_i}}{2X_{d_i}^{'}\left(X_{d_i} - X_{d_i}^{'}\right)}E_{q_i}^{'2} - \sum_{i=1}^{n}\sum_{k=n+1}^{n+m}B_{ki}e^{v_i+v_k}\cos\left(\theta_i - \gamma_k\right) - ...$$

$$\sum_{k=n+1}^{n+m}\sum_{k=n+1}^{n+m}B_{kl}e^{v_k+v_l}\cos\left(\gamma_k - \gamma_l\right)$$

The Hamilton function above includes the power system's total energy, with the possibility to express it as a dissipative Hamilton system as shown below, [3-5]. From the Hamiltonian function (7)-(8),

$$\nabla_x H\left(x,z\right) = \begin{bmatrix} \dfrac{\partial H\left(x,z\right)}{\partial\delta_i} \\ \dfrac{\partial H\left(x,z\right)}{\partial\omega_i} \\ \dfrac{\partial H\left(x,z\right)}{\partial E_{q_i}^{'}} \end{bmatrix} = \begin{bmatrix} P_{e_i} \\ \omega_0 M_i\left(\omega_i - 1\right) \\ -\dfrac{T_{d0_i}^{'}}{x_{d_i} - x_{d_i}^{'}}\phi_i \end{bmatrix} \quad (9)$$

Thus, the power system exhibits the dissipative Hamilton representation in (10).

$$\begin{bmatrix} \dot{\delta}_i \\ \dot{\omega}_i \\ \dot{E}_{q_i}^{'} \end{bmatrix} = \begin{bmatrix} 0 & \dfrac{1}{M_i} & 0 \\ -\dfrac{1}{M_i} & -\dfrac{D_i}{M_i^2\omega_0} & 0 \\ 0 & 0 & -\dfrac{x_{d_i} - x_{d_i}^{'}}{\tau_{d0_i}^{'}} \end{bmatrix} \begin{bmatrix} P_{e_i} \\ \omega_0 M_i\left(\omega_i - 1\right) \\ -\dfrac{\tau_{d0_i}^{'}}{x_{d_i} - x_{d_i}^{'}}\phi_i \end{bmatrix} + ...$$

$$\begin{bmatrix} 0 & 0 \\ \dfrac{1}{M_i} & 0 \\ 0 & \dfrac{1}{T_{d0_i}^{'}} \end{bmatrix} \begin{bmatrix} P_{m_i} \\ E_{f_i} \end{bmatrix}$$

$$0 = \frac{\partial H(x,z)}{\partial z}$$

... (10)

Let

$$J(x,z) = \begin{bmatrix} 0 & \dfrac{1}{M_i} & 0 \\ -\dfrac{1}{M_i} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix};$$

$$R(x,z) = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \dfrac{D_i}{M_i^2\omega_0} & 0 \\ 0 & 0 & \dfrac{X_{d_i} - X_{d_i}^{'}}{T_{d0_i}^{'}} \end{bmatrix} \quad (11)$$

Then, the dissipative realization for a structure preserving the network is complete. It is worth noting that *J(x, z)* is a skew symmetric matrix, and *R(x, z)* is a positive semi-definite matrix.

III. Geometric Controller

A well designed controller must have robust characteristics with regard to changes in parameter and operating conditions as well as disturbances. The modern approach for controller design by the procedure of feedback linearization is based on the theory of nonlinear control systems [6-14]. With this technique, compensation schemes are adopted to partially or totally cancel nonlinearities presented in state-input or input–output relationships, so that output or state dynamics are transformed into equivalent linear time invariant dynamics. A new input stabilizes the state or output through standard linear techniques by imposing a linear dynamic described by a desired time variant trajectory (tracking design) or, more simply, by a time invariant trajectory (stabilization design). A drawback with this procedure is represented by computational difficulties due to the system dimension, which can, however, be overcome by neglecting important dynamic elements or adopting reduced order system models. The problem of the unavailability of some input signals has been partially solved [6-23].

Let assume a *p*-inputs *p*-outputs plant, expressed by

$$\begin{cases} \dot{x} = f(x) + g_1\left(x\right)u_1 + g_2\left(x\right)u_2 + ... + g_p\left(x\right)u_p \\ y_1 = h_1\left(x\right); \quad y_2 = h_2\left(x\right); \ldots; y_p = h_p\left(x\right) \end{cases} \quad (12)$$

The control objective consists on synthesize a controller able to take outputs $[y_1, y_2, \ldots, y_p]^T$ toward the desired value $[y_{d1}, y_{d2}, \ldots, y_{dp}]^T$:

$$y(t)=\begin{bmatrix} y_1(t)\\ y_2(t)\\ \vdots \\ y_p(t)\end{bmatrix} \rightarrow y_d(t)=\begin{bmatrix} y_{d1}(t)\\ y_{d2}(t)\\ \vdots \\ y_{dp}(t)\end{bmatrix} \quad (13)$$

The control problem consists on evaluate inputs $u(t) = [u_1(t), u_2(t),..., u_p(t)]^T$ in order to satisfy the objective. The output and control variables relationship is expressed by [6-8]:

$$\begin{bmatrix} y_1^{(\nu 1)}\\ y_2^{(\nu 2)}\\ \vdots \\ y_p^{(\nu p)}\end{bmatrix} = \begin{bmatrix} L_f^{(\nu 1)}h_1\\ L_f^{(\nu 2)}h_2\\ \vdots \\ L_f^{(\nu p)}h_p\end{bmatrix} + A(x)\begin{bmatrix} u_1\\ u_2\\ \vdots \\ u_p\end{bmatrix} \quad (14)$$

where

$$A(x)=\begin{bmatrix} L_{g1}L_f^{(\nu 1-1)}h_1 & L_{g2}L_f^{(\nu 1-1)}h_1 & \cdots & L_{gp}L_f^{(\nu 1-1)}h_1\\ L_{g1}L_f^{(\nu 2-1)}h_2 & L_{g2}L_f^{(\nu 2-1)}h_2 & \cdots & L_{gp}L_f^{(\nu 2-1)}h_2\\ \vdots & \vdots & \ddots & \vdots \\ L_{g1}L_f^{(\nu p-1)}h_p & L_{g2}L_f^{(\nu p-1)}h_p & \cdots & L_{gp}L_f^{(\nu p-1)}h_p \end{bmatrix} \quad (15)$$

ν1 is the smaller integer such that the derivative $y_j^{(\nu i)}$ depends at least from one input $[u_1, u_2,..., u_p]^T$;

$$L_f^{(\nu i)}h_i = \frac{\partial^{(\nu i)} h_i(x)}{\partial x^{(\nu i)}} f(x)$$
$$L_{gi}L_f^{(\nu j)}h_j = \frac{\partial L_f^{(\nu j-1)}h_j}{\partial x} g_i(x) \quad (16)$$

are the Lie derivatives [6]. The control law becomes,

$$u=\begin{bmatrix} u_1\\ u_2\\ \vdots \\ u_p\end{bmatrix} = -A^{-1}(x)\begin{bmatrix} L_f^{(\nu 1)}h_1\\ L_f^{(\nu 2)}h_2\\ \vdots \\ L_f^{(\nu p)}h_p\end{bmatrix} +$$

$$A^{-1}(x)\begin{bmatrix} y_{1d}^{(\nu 1)} + \sigma_{(\nu 1-1)}{}^1 (y_{1d}^{(\nu 1-1)} - y_1^{(\nu 1-1)}) + \sigma_{(\nu 1-2)}{}^1 (y_{1d}^{(\nu 1-2)} - y_1^{(\nu 1-2)})... \\ + \cdots + \sigma_0^1 (y_{1d} - y_1) \\ \vdots \\ y_{pd}^{(\nu p)} + \sigma_{(\nu p-1)}{}^p (y_{pd}^{(\nu p-1)} - y_p^{(\nu p-1)}) + \sigma_{(\nu p-2)}{}^p (y_{pd}^{(\nu p-2)} - y_p^{(\nu p-2)})... \\ + \cdots + \sigma_0^p (y_{pd} - y_p) \end{bmatrix}$$

… (17)

The design parameters σ_1^k are setting up in such a way that the followings are Hurwitz polynomials,

$$s^{(\nu 1)} + \sigma^1_{(\nu 1-1)} s^{(\nu 1-1)} + \cdots + \sigma_0{}^1 = 0$$
$$s^{(\nu 2)} + \sigma^2_{(\nu 2-1)} s^{(\nu 2-1)} + \cdots + \sigma_0{}^2 = 0$$
$$\vdots \quad (18)$$
$$s^{(\nu p)} + \sigma^p_{(\nu p-1)} s^{(\nu p-1)} + \cdots + \sigma_0{}^p = 0$$

Thus, the control objective is satisfied,

$$\tilde{y}_1(t) \rightarrow 0$$
$$\tilde{y}_2(t) \rightarrow 0$$
$$\vdots \quad (19)$$
$$\tilde{y}_p(t) \rightarrow 0$$

where $\tilde{y}_j(t) = y_{jd}(t) - y_j(t)$.

In this paper, taken excitation voltages (E_{fd}) and mechanical torques (P_m) as inputs, and terminal voltages (V_t) and velocity (ω) as outputs, the state space realization for the i-th generator can be rewritten by [24]

$$\dot{x}_i(t) = f_i(x(t)) + g_{1i}u_{1i} + g_{2i}u_{2i}$$
$$= f_i(x_i(t)) + \begin{bmatrix} 0\\ 0\\ 1/T'_{d0i}\end{bmatrix} E_{fdi} + \begin{bmatrix} 0\\ 1/M_i\\ 0\end{bmatrix} P_{mi} \quad (20)$$
$$y_{1i}(t) = h_1(x_i) = |V_{ti}| = \sqrt{v^2_{di} + v^2_{qi}}$$
$$y_{2i}(t) = h_2(x_i) = \omega_i$$

where $v_{di} = x'_{qi}\, i_{qi}$; $v_{qi} = E'_{qi} - x'_{di}\, i_{di}$; in this case, ν1 = ν2 = 1.

A. Improved formulation

Pragmatically, the field voltage (E_{fd}) and mechanical power (P_m) are not handled variables. Thus, in this paper first order regulators for both voltage and speed are taken into account. Additional inputs (u_1 and u_2) are added to include the geometric controllers,

$$\frac{d}{dt}E_{fd} + \frac{1}{\tau_e}E_{fd} = \frac{K_e}{\tau_e}\left(V_{Tref} - V_T + u_1\right) \quad (21)$$

$$\frac{d}{dt}P_m + \frac{1}{\tau_g}P_m = \frac{K_g}{\tau_g}\left(\omega_{ref} - \omega + u_2\right) \quad (22)$$

Thus, the state space representation becomes

$$\begin{bmatrix} \dot{\delta}_i \\ \dot{\omega}_i \\ \dot{E}'_{q_i} \\ \dot{E}_{fd_i} \\ \dot{P}_{m_i} \end{bmatrix} = \begin{bmatrix} \omega_0(\omega_i - 1) \\ \frac{-D_i}{M_i}(\omega_i - 1) + \frac{1}{M_i}\left(P_{m_i} - P_{e_i}\right) \\ -\phi_i + \frac{1}{T'_{d0_i}}E_{fd_i} \\ -\frac{1}{T_{e_i}}E_{fd_i} - \frac{K_{e_i}}{T_{e_i}}(V_{T_i} - V_{Tref\,i}) \\ -\frac{1}{T_{g_i}}P_{m_i} - \frac{K_{g_i}}{T_{g_i}}(\omega_i - \omega_{ref\,i}) \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{K_{e_i}}{T_{e_i}} & 0 \\ 0 & \frac{K_{g_i}}{T_{g_i}} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

… (23)

This formulation give rise to a robust pragmatic controller.

IV. Case Study

A 10-machines 39-buses power system [1] is utilized to demonstrate the proposed technique. A three-phase fault is simulated at 0.1 s to evidence the transient system's behavior.

The proposed controller's performance is compared to geometric controls responses not including the first order controllers (20); such absence would represent the ideal case.

Figs. 1-2 show the transient behavior of voltage magnitude at bus 8, the angular velocity of generator 3, respectively, after a three-phase fault at bus 17, without tripping any line. In this case, generators have geometric controllers designed without take into account the first order control on excitation voltage and mechanical power. The impact of controllers is such that from unstable behavior, the transient process progresses softly.

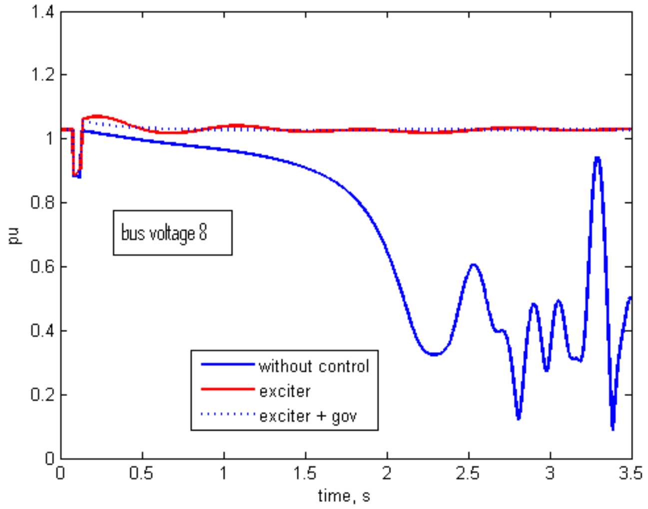

Fig. 1. Bus voltage 8. Fault at bus 17.

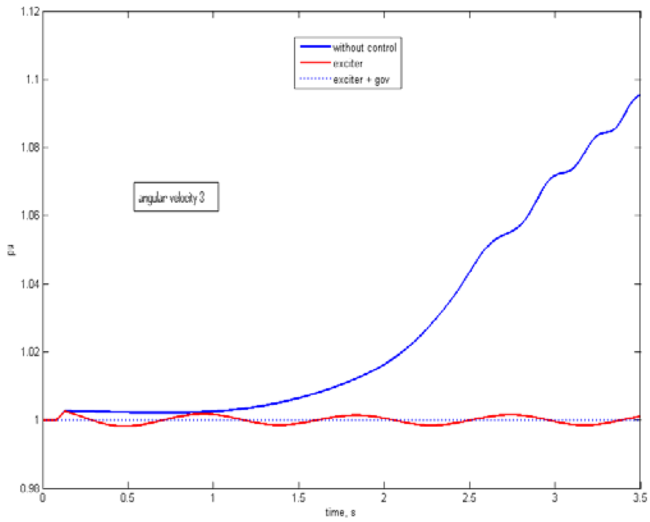

Fig. 2. Angular velocity 3. Fault at bus 17.

On the other hand, Figs. 3-4 display the transient process of voltage magnitude at bus 1, and the angular velocity of the generator 10, respectively. Generators include geometric controllers designed taking as inputs the reference values of the speed and voltage regulators. As expected, signals undergo a longer transient before attain a steady state.

Now, the nominal condition is considered [1]. However, line 14-15 is out of service. Fig. 5 exhibits the response of voltage magnitude at bus 6, after a fault at bus 35 applied at 0.1 s. Similarly, Fig. 6 depicts the angular velocity 7, under the same conditions, but with the first order dynamic included. As before, both controllers induce a soft transient.

Thus, the proposed controllers are able to respond appropriately under different operating conditions, adding damping to power oscillations. Moreover, by limiting the excursions of reference values due to corrective actions, may conduct to pragmatic nonlinear controllers for generating units.

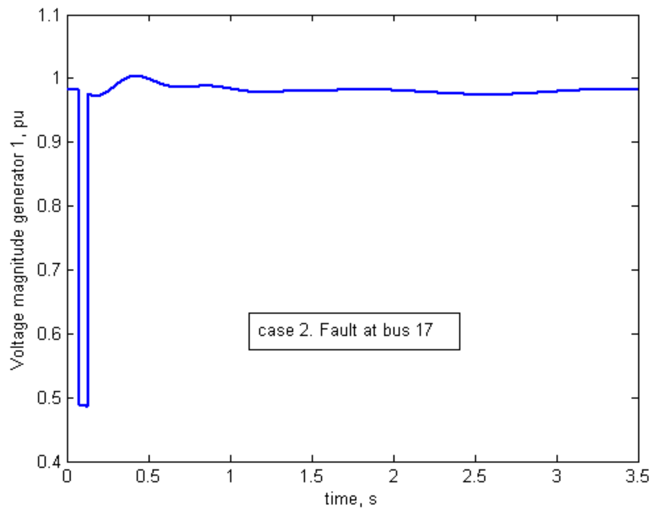

Fig. 3. Bus voltage 1. Fault at bus 17. First order controller dynamics included

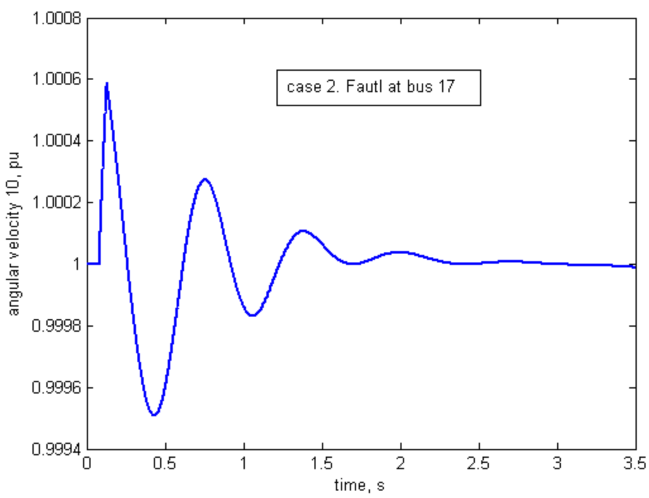

Fig. 4. Angular velocity 10. Fault at bus 17. First order controller dynamics included

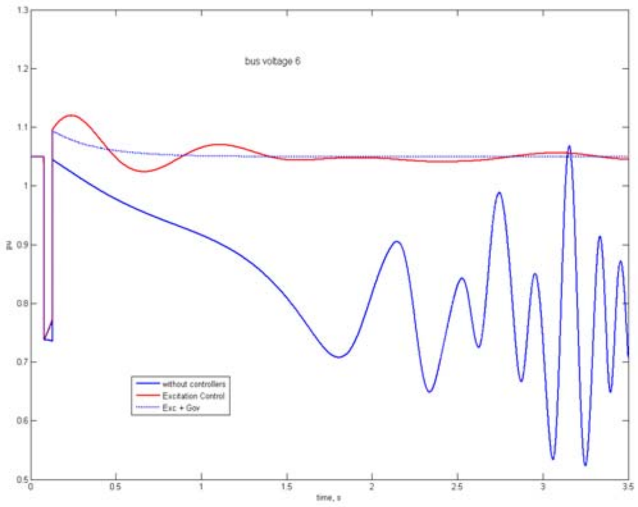

Fig. 5. Bus voltage 6. Fault at bus 35.

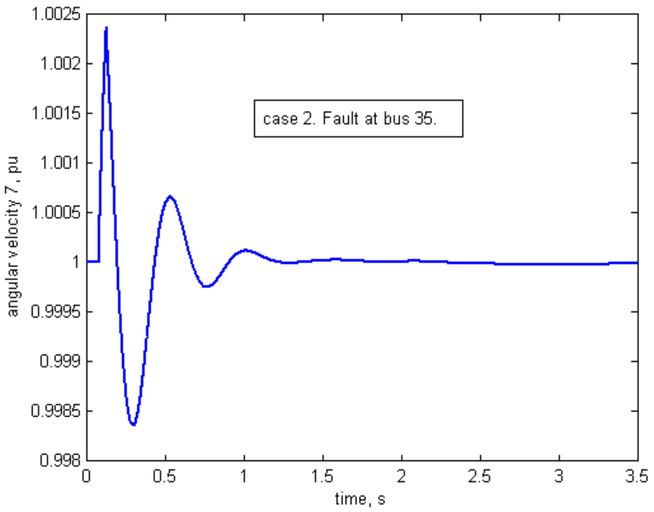

Fig. 6. Angular velocity 7. Fault at bus 35. First order controller dynamics included

V. CONCLUSIONS

The performance of the proposed nonlinear controllers is independent of the system's operating point. It is noteworthy that the nonlinear controllers ensure cancellation of the interactions among subsystems, providing additional damping with respect to conventional controllers. These controllers are not restricted to a particular power system, i.e. they can be applied to general power systems.

Transparent multi-variable nonlinear controllers have been designed to achieve simultaneously transient stability enhancement and post-fault voltage regulation improvement of the generator terminal voltage in multi-machine power systems.

The proposed method effectively decentralizes the feedback controllers. Furthermore, the signals used to apply the corrective actions to generating units can be handled without difficulties, giving rise to the possibility of implementing on actual generating units.

Simulation results demonstrate that the proposed controller is able to achieve that the mechanical dynamics and the generator terminal voltages become robust under large disturbances.

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