

Dynamic Voltage Stabilization of Stand-Alone Wind Energy Schemes

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Abstract—Voltage stability is one of the serious problems in stand-alone wind energy schemes utilizing the induction generator especially under wind excursion and load variation. This paper presents a novel low cost Modulated Power Filter Compensator FACTS based-MPFC for a stand-alone green energy renewable wind energy conversion systems using self-excited low cost squirrel-cage induction generator (SEIG) driven by a wind turbine and connected to balanced/unbalanced load utility systems. A novel control scheme based on a tri-loop dynamic error driven error scaled regulator is applied to ensure both source and load bus voltage stabilization and enhance the power quality. The MPFC-FACTS scheme is digitally simulated and satisfactory results were obtained showing the applicability of the novel FACTS Stabilization Power Filter for supplying power to different unbalanced loads such as isolated villages, heating, water pumping, ventilation and air conditioning.

Index Terms—Wind energy, Modulated power filter compensation-MPFC-FACTS, scaled regulation, Power Quality, Induction Generator, unbalanced load.

I. INTRODUCTION

Wind energy is the fastest growing source of renewable green electricity in the world. Wind-generated electricity is rapidly expanding, and is helping to ease the dependency on increasing oil, and gas prices. In addition, wind-generated electricity is now powering homes and businesses with clean, reliable, and efficient pollution free green electricity.

Wind energy is now being used widely in modern electrical systems either as stand-alone applications or a utility connected wind farm installation. In many applications the wind energy systems are combined with other green power renewable types such as photovoltaic (PV), and possibly fuel cell systems. For large utility-scaled wind sources using wind farms with the range (100-300 MW), a large number of wind turbines are clustered into an area. Several independent electricity providers and suppliers today use the wind farms to supply power to their remote area customers [1]. With this increased use of wind as an energy resource it is becoming important to address both reliability, and security of wind power conversion.

This paper investigates a novel stabilization scheme that ensures voltage stabilization, efficient power utilization and enhances power Quality for a stand-alone wind energy conversion scheme.

II. SYSTEM DESCRIPTION

The stand-alone renewable green wind energy system is connected to the local load bus over a radial transmission line comprising the following main components, as shown in Figure 1.

- i. Wind turbine
- ii. Gear box
- iii. Step up and step down transformers
- iv. Distribution power lines
- v. Induction or synchronous generator
- vi. Stabilization interface scheme and stabilization controller
- vii. The hybrid electric load.

The self excited squirrel-cage induction generator used in the proposed stand-alone wind energy system is coupled with a stand-alone wind turbine and connected to a utility network consisting of various types of hybrid loads, which consist of about 40% linear load, 40% nonlinear load, and 20% motorized load, as shown in Figure 1. Due to its low-cost and less maintenance [5], the squirrel cage induction generator is chosen as the main power generator. Any stand-alone wind energy conversion scheme is usually employed to supply power to hybrid loads such as passive, motorized and nonlinear type loads, which can be water pumping, ventilation, air-circulation/air-conditioning, and many different mechanical Loads. These loads are generally insensitive to small frequency variations. The frequency excursions can vary within a limited range of \pm (5%–10%) maximum, which is not considered very adverse to stand-alone localized /motorized loads [6]. The variations in frequency can also be minimized using dynamic type loads/dump/switched load strategies [7]. Voltage stability is a serious problem for any standalone wind energy conversion scheme using induction generator, especially under severe wind gusting and dynamic load variation [8].

The Simulink functional model of the three phase AC study test system is depicted in Figure 2. Modulated power filters and control strategies for dynamic PWM generator are given in Figures 3 and 4, respectively.

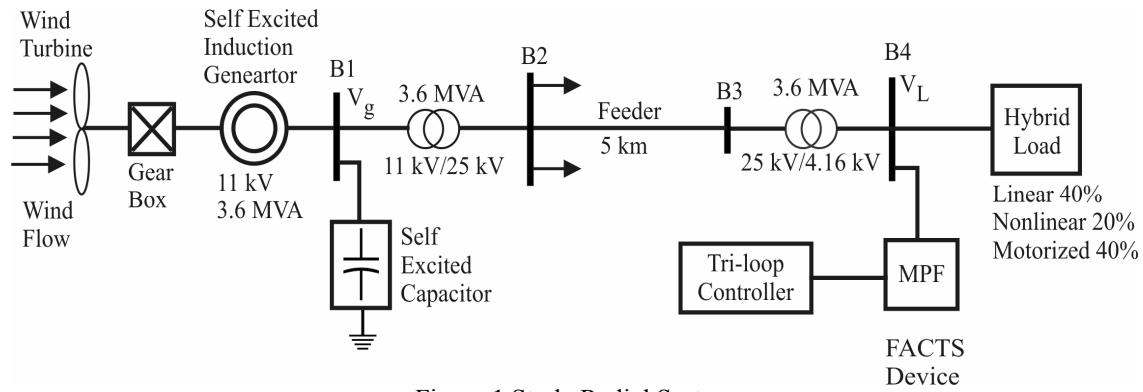


Figure.1 Study Radial System

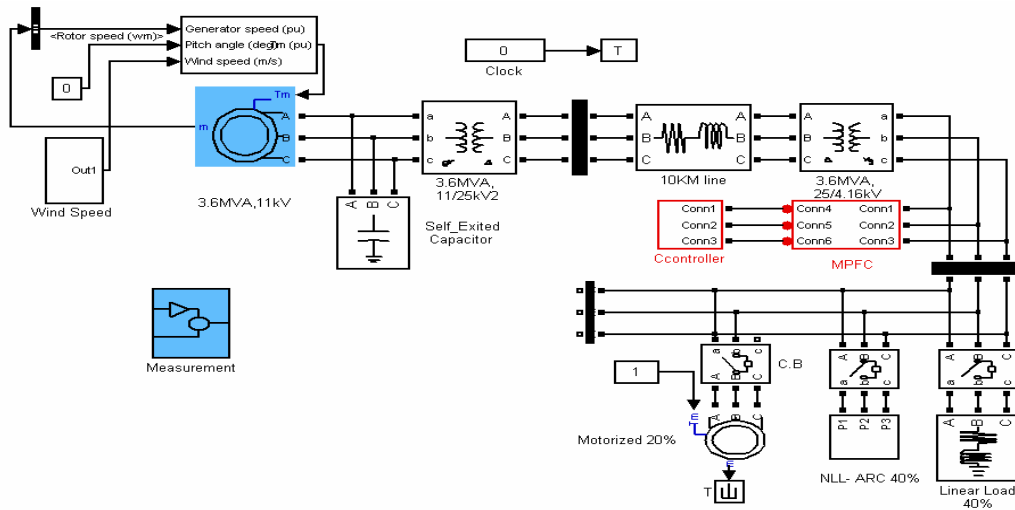


Figure 2. Digital MATLAB-Simulation functional model of full AC study system

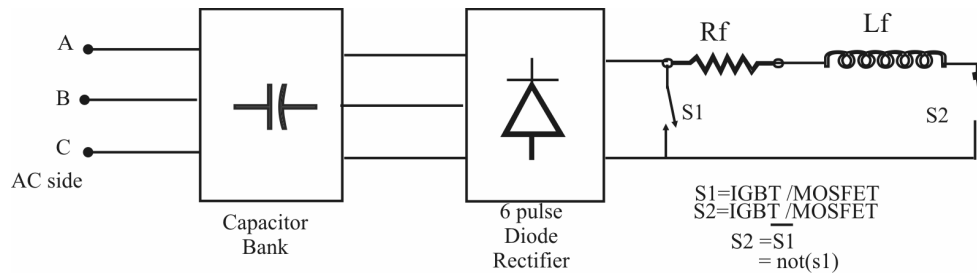


Figure 3. Modulated Power Filter Compensator.

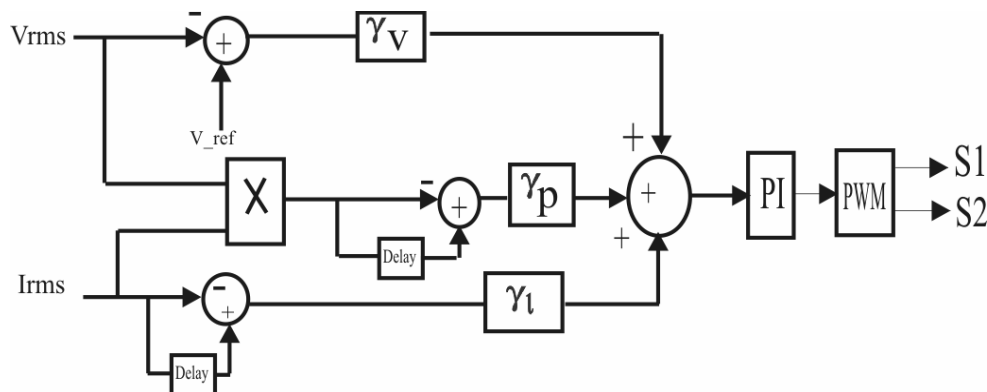


Figure 4. Dynamic tri-loop error driven PI controller.

III. CONTROL STRATEGY

The novel dynamic switching tri-loop dynamic error driven Proportional plus Integral control comprises three basic regulating loops. These tri-loops compute the errors for RMS load voltage, RMS load current and dynamic power tracking as shown in Figure 4. The three regulating loops play a combined role for voltage stabilization, efficient energy utilization, power factor, and flickers migration. The functional behaviors of these tri-loops are summarized below.

1. The rms load voltage is the main loop for voltage stabilization. The control signal weight γ_v is selected as 1.
 2. The rms load current is the dynamic error coordinative type minimum rms load current excursion. The weight γ_i is selected as 0.5, to include the changes and excursions in load current.
 3. The dynamic power error loop with the weight γ_p selected as 1 to ensure maximum power utilization by taking the power changes into account.
- The total error signal (e_t) is the sum of these three basic dynamically scaled loop errors that presents by:

$$e_t = \gamma_v \cdot e_v + \gamma_i \cdot e_i + \gamma_p \cdot e_p \quad (1)$$

The loop weighing factors are assigned to ensure loop time scaling and dominant loop (1) control action.

The total error signal to ensure maximum power utilization of the tri-loop is driven through a PI controller that is used to compensate the dynamic total error in order to provide control signal, which is then converted to degrees as phase angles. This phase angles are then sent to the Pulse Width Modulated (PWM) generator through saturation to adjust the sequence of the two IGBT/Diode switch triggering which is shown in Figure 4. The control gains Kp, and Ki are selected using a guided trial and error method to minimize an objective function [14], which is used for flickers migration, the voltage stabilization enhancement, and efficient energy utilization. The novel tri-loop dynamic controller is validated for voltage stabilization and dynamic reactive compensation using Matlab-Simulink-SimPower Toolbox software environment. The selected control parameters are given in the Table 1.

TABLE 1
SELECTED PARAMETERS FOR THE STAND-ALONE WIND ENERGY CONVERSION SCHEME STABILIZATION

Wind Turbine Model		Motorized load	
Nominal mechanical output power	3.6MW	Motorized load	2.6 [MVA]
Mean wind speed	10 m/s	6 pulse Diode	
Localized capacitor bank per phase	30 μ F		
Stator resistance of induction generator	0.016 pu		
Mutual inductance of induction generator (Lm)	3.65 pu	Snubber resistance Rs	1e5 Ω
Rotor resistance	0.015 pu	Snubber resistance Cs	inf
Transmission line (10 km)		Linear Load	
Resistance	1.0127*10 Ω	Active Power	1 MVA
La , Lb and Lc	(0.997e-3)*10/60/2/pi mH	Reactive Power	0.75e6 MVA
MPF Filter		Transformel	
Rf	2 Ω	Primary winding	11 kV
Lf	20.14 mH	Secondary winding	25 kV
Fixed Capacitor	95 μ F	Transformer 2	
IGBT resistance Ron	1e-3 Ω	Primary winding	25 kV
Snubber resistance Rs	10e5 Ω	Secondary winding	4.16 kV
Nonlinear Load	0.4e6 MW		

IV. DIGITAL SIMULATION RESULTS

The unified AC system model is subject to the following load disturbances as:

- (i) Linear load 40% at 0.1 sec.
- (ii) Nonlinear load 20% at 0.12 sec (connected at 0.12 sec, disconnected at 0.5 and connected again at 0.7sec).
- (iii) Motorized load 40% at 0.15 sec.

Figures 5 and, 6 show the digital simulation dynamic responses at the source side and Figures 7,8 depict the digital simulation dynamic responses at the load bus. The results indicate an improvement in the voltage, current, reactive power and power factor as indicated in Table 2 and 3 for two cases of without and with MPFC-FACTS device.

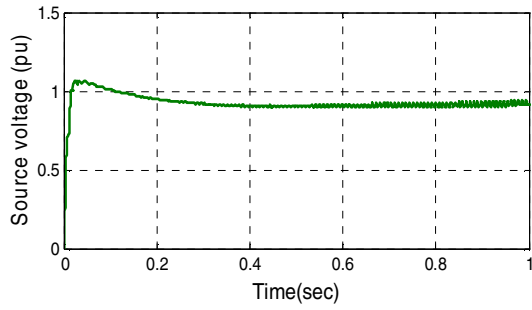
Table 2 shows an improvement at source bus in voltage stabilization by 12%, and the power factor increased by 1% while the active power increased by 2%

And Table 3 shows a significant enhancement in bus voltage

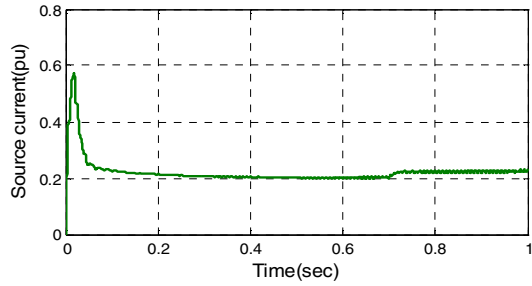
stabilization by 17% at load bus, and increase in the active power by 7% with load current boost of 8%. However, special care should be taken in selecting the MPFC parameters to avoid possible parallel resonance with the induction generator or system inductance.

TABLE 2
DYNAMIC SIMULATION RESULTS WITHOUT AND WITH USING MPFC AT THE SOURCE BUS

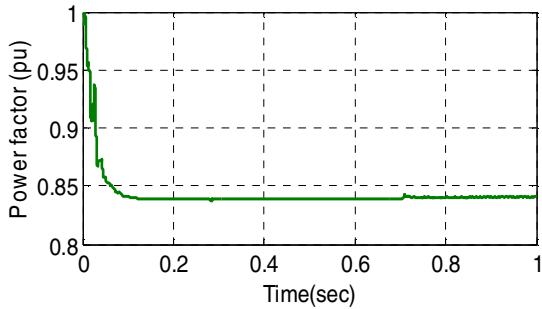
Response Name	Without MPFC	With MPFC
Source voltage	0.88 pu	1.07 pu
Source current	0.22 pu	0.23 pu
Power factor at source bus	0.83 pu	0.84 pu
Active power at source bus	0.20 pu	0.22pu



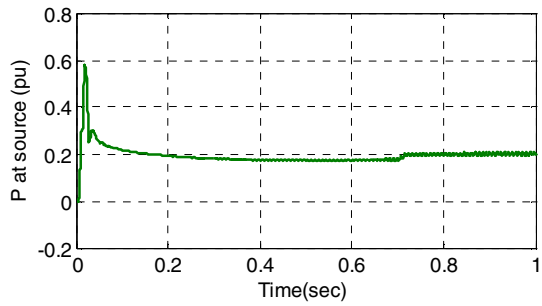
(a) Source voltage (pu) vs Time (sec).



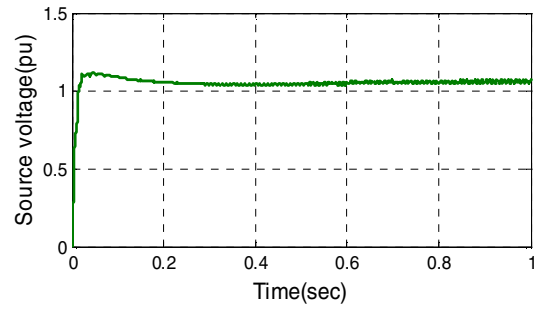
(b) Source Current (pu) vs. Time (sec).



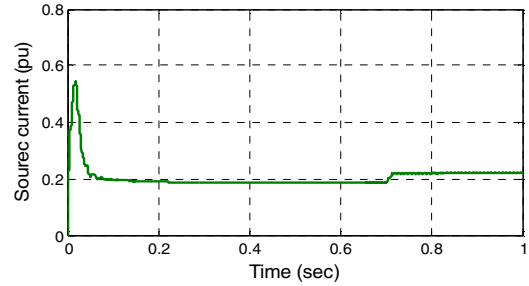
(c) Power factor vs. Time (sec).



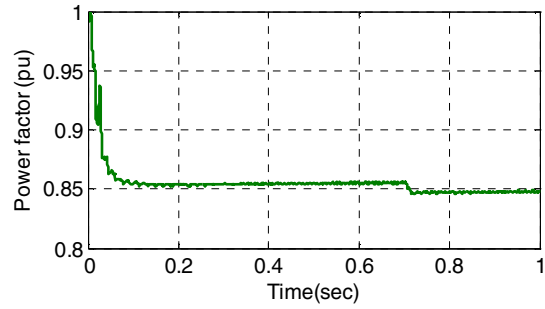
(c) Active power (pu) vs. Time (sec).



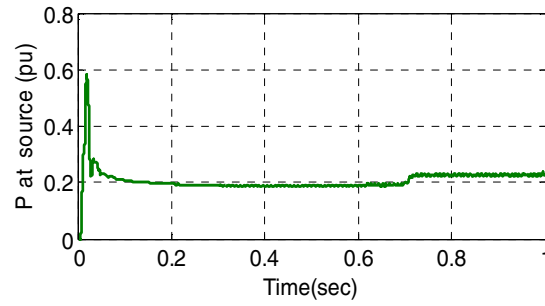
(a) Source voltage (pu) vs Time (sec).



(b) Source current (pu) vs. Time (sec).



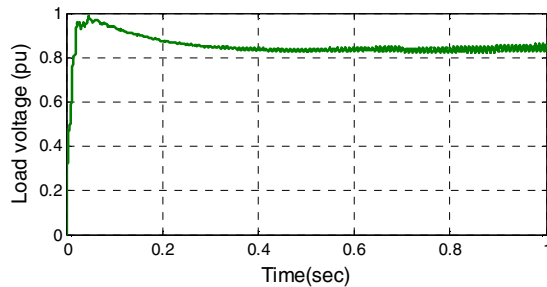
(c) Power factor vs. Time (sec).



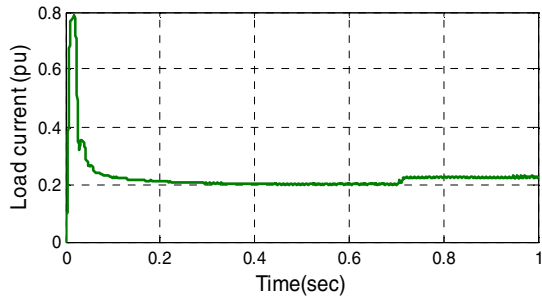
(d) Active power (Pu) vs. Time (sec).

Figure 5. Dynamic responses without MPFC at Source Side

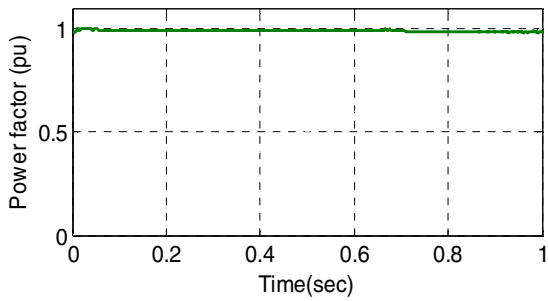
Figure 6. Dynamic responses with MPFC at Source Side



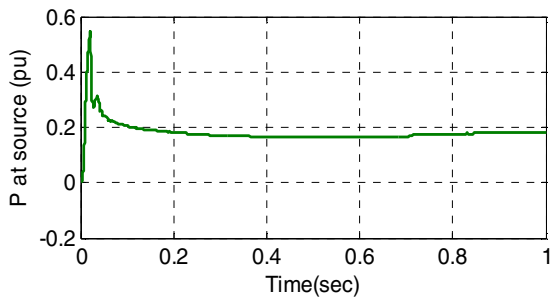
(a) Load bus voltage (pu) vs. Time (sec).



(b) Load current (pu) vs. Time (sec).

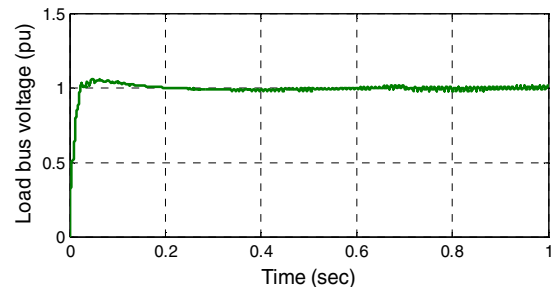


(c) Power factor (pu) vs. Time (sec).

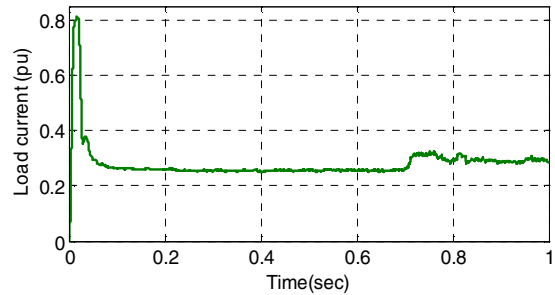


(d) Active power (pu) vs. Time (sec).

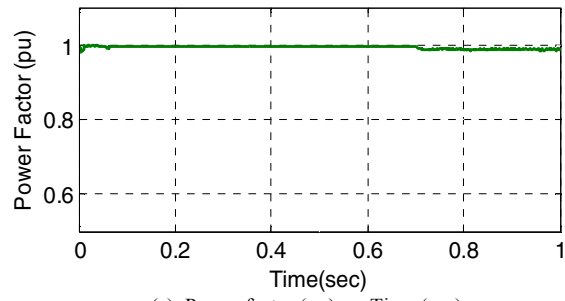
Figure 7 Dynamic responses without MPFC at Load side



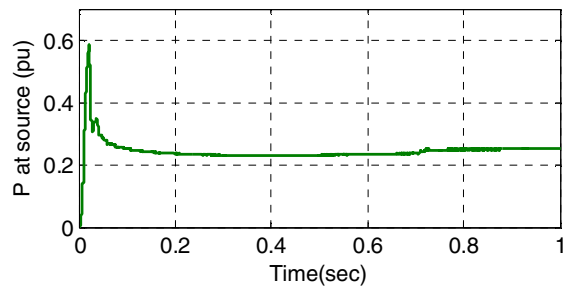
(a) Load bus voltage (pu) vs. Time (sec).



(b) Load current (pu) vs. Time (sec).



(c) Power factor (pu) vs. Time (sec).



(c) Active power (pu) vs. Time (sec).

Figure 8 Dynamic responses with MPFC at Load side

TABLE 3
DYNAMIC SIMULATION RESULT WITHOUT AND WITH USING MPFC AT THE
LOAD BUS

	Without MPFC	With MPFC
Load bus voltage	0.83 pu	1.00 pu
Load bus current	0.20 pu	0.28 pu
Load bus power factor	0.98 pu	0.98pu
Load bus active power	0.18 pu	0.25pu

V. CONCLUSIONS

This paper presents a novel low cost FACTS based Modulated power filter Compensator (MPFC) scheme for bus voltage stabilization and efficient energy utilization for stand-alone wind energy driven squirrel cage induction generator system. The MPFC-scheme utilizes a sinusoidal pulse width modulation strategy driven by a tri-loop error driven control scheme. The tri loop dynamic controller is designed to ensure combined voltage stabilization and efficient power utilization as well as improved power factor. The low-cost Modulated Power Filter Compensator MPFC Scheme developed by the

First Author scheme utilizes a pulse width modulation strategy driven by a dynamic multi loop action error driven regulator scheme. The novel controller is designed to ensure combined Multi stabilization and efficient operation of the renewable Green Energy Utilization Scheme.

Digital simulation using Matlab-Simulink-Sim-Power Software Environment results were validated and simulated, showing that MPFC-Modulated power filter is effective in voltage stabilization and efficient utilization.

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