

ACTAS

DE LAS

XXXVIII Jornadas de Automática

Gijón · Palacio de Congresos · 6, 7 y 8 de Septiembre de 2017



Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo



CEA
Comité Español
de Automática

Colabora

Gijón
Convention Bureau

Actas de

XXXVIII

Jornadas de Automática

© 2017 Universidad de Oviedo
© Los autores

Servicio de Publicaciones de la Universidad de Oviedo
Campus de Humanidades. Edificio de Servicios. 33011 Oviedo (Asturias)
Tel. 985 10 95 03 Fax 985 10 95 07
[http: www.uniovi.es/publicaciones](http://www.uniovi.es/publicaciones)
servipub@uniovi.es

DL AS 2749-2017

ISBN: 978-84-16664-74-0

Todos los derechos reservados. De conformidad con lo dispuesto en la legislación vigente, podrán ser castigados con penas de multa y privación de libertad quienes reproduzcan o plagien, en todo o en parte, una obra literaria, artística o científica, fijada en cualquier tipo y soporte, sin la preceptiva autorización.

Prefacio

Las *Jornadas de Automática* se celebran desde hace **40 años** en una universidad nacional facilitando el encuentro entre expertos en esta área en un foro que permite la puesta en común de las nuevas ideas y proyectos en desarrollo. Al mismo tiempo, propician la siempre necesaria colaboración entre investigadores del ámbito de la Ingeniería de Control y Automática, así como de campos afines, a la hora de abordar complejos proyectos de investigación multidisciplinares.

En esta ocasión, las Jornadas estarán organizadas por la Universidad de Oviedo y se han celebrado del 6 al 8 de septiembre de 2017 en el Palacio de Congresos de Gijón, colaborando tanto la Escuela Politécnica de Ingeniería de Gijón (EPI) como el Departamento de Ingeniería Eléctrica, Electrónica de Computadores y de Sistemas del que depende el Área de Ingeniería de Sistemas y Automática.

Además de las habituales actividades científicas y culturales, esta edición es muy especial al celebrarse el **50 aniversario de la creación de CEA**, Comité Español de Automática. Igualmente este año se conmemora el 60 aniversario de la Federación Internacional del Control Automático de la que depende CEA. Así se ha llevado a cabo la presentación del libro que se ha realizado bajo la coordinación de D. Sebastián Dormido, sobre la historia de la Automática en España en una sesión en la que han participado todos los ex-presidentes de CEA conjuntamente con el actual, D. Joseba Quevedo.

Igualmente hemos contado con la presencia de conferenciantes de prestigio para las sesiones plenarias, comunicaciones y ponencias orales en las reuniones de los 9 grupos temáticos, contribuciones en formato póster. Se ha celebrado también el concurso de CEABOT, así como una nueva Competición de Drones, con el ánimo de involucrar a más estudiantes de últimos cursos de Grado/Máster.

En el marco de las actividades culturales programadas se ha podido efectuar un recorrido en el casco antiguo situado en torno al Cerro de Santa Catalina y visitar la Laboral.

Gijón, septiembre de 2017

Hilario López
Presidente del Comité Organizador

Program Committee

Antonio Agudo	Institut de Robòtica i Informàtica Industrial
Rosa M Aguilar	University of La Laguna.
Luciano Alonso	University of Cantabria
Ignacio Álvarez García	Universidad de Oviedo
Antonio Javier Artuñedo García	Centre for Automation and Robotics (CSIC-UPM)
José M. Azorín	Miguel Hernandez University of Elche
Pedro Balaguer	Universitat Jaume I
Antonio Javier Barragán Piña	Universidad de Huelva
Alfonso Baños	Universidad de Murcia
Guillermo Bejarano	University of Seville
Gerardo Beruvides	Centro de Automática y Robótica
Carlos Bordons	University of Seville
Jose Manuel Bravo	University of Huelva
Jose Luis Calvo-Rolle	University of A Coruña
Fernando Castaño Romero	Centro de Automática y Robótica (UPM -CSIC)
José Luis Casteleiro-Roca	University of Coruña
Alvaro Castro-Gonzalez	Universidad Carlos III de Madrid
Ramon Costa-Castelló	Universitat Politècnica de Catalunya
Abel A. Cuadrado	University of Oviedo
Arturo De La Escalera	Universidad Carlos III de Madrid
Emma Delgado	Universidad de Vigo
Jose-Luis Diez	Universitat Politecnica de Valencia
Manuel Domínguez	Universidad de León
Juan Manuel Escaño	Universidad de Sevilla
Mario Francisco	University of Salamanca
Maria Jesus Fuente	Universidad de Valladolid
Juan Garrido	Universtiy of Cordoba
Antonio Giménez	Universidad de Almeria
Evelio Gonzalez	Universidad de La Laguna
José-Luis Guzmán	Universidad de Almería
Rodolfo Haber	Center for Automation and Robotics (UPM-CSIC)
César Ernesto Hernández	Universidad de Almería
Eloy Irigoyen	UPV/EHU
Agustin Jimenez	Universidad PolitÁcnica de Madrid
Emilio Jiménez	University of La Rioja
Jesus Lozano	Universidad de Extremadura
Jorge Luis Madrid	Centro de Automática y Robótica
Luis Magdalena	Universidad Politécnic de Madrid
David Martin Gomez	Universidad Carlos III de Madrid
Fernando Matia	Universidad Politecnica de Madrid
Joaquim Melendez	Universitat de Girona
Juan Mendez	Universidad de La Laguna
Luis Moreno	Universidad Carlos III de Madrid
María Dolores Moreno Rabel	Universidad de Extremadura
David Muñoz	Universidad de Sevilla
Antonio José Muñoz-Ramirez	Universidad de Málaga
Jose Luis Navarro	Universidad Politecnica de Valencia
Manuel G. Ortega	University of Seville
Andrzej Pawlowski	UNED
Mercedes Perez de La Parte	University of La Rioja
Ignacio Peñarrocha	Universitat Jaume I de Castelló, Spain
José Luis Pitarch	Universidad de Valladolid

Daniel Pérez	University of Oviedo
Emilio Pérez	Universitat Jaume I
Juan Pérez Oria	Universidad de Cantabria
MiguelÁngel Ridao	Universidad de Sevilla
Gregorio Sainz-Palmero	Universidad de Valladolid
Antonio Sala	Universitat Politecnica de Valencia
Ester Sales-Setién	Universitat Jaume I
Jose Sanchez	UNED
Javier Sanchis Saez	Universitat Politecnica de Valencia (UPV)
José Pedro Santos	ITEFI-CSIC
Matilde Santos	Universidad Complutense de Madrid
Alvaro Serna	University of Valladolid
José Enrique Simó	Universidad Politécnica de Valencia
José A. Somolinos	ETS I Navales. Universidad Politecnica de Madrid
Fernando Tadeo	Univ. of Valladolid
Alejandro Tapia	Universidad de Loyola Andalucía
David Tena	Universitat Jaume I
Jesús Torres	Universidad de La Laguna
Pedro M. Vallejo	Universidad de Salamanca
Guilherme Vianna	Universidad de Sevilla
Alejandro Vignoni	AI2 - UPV
Ramón Vilanova	UAB
Francisco Vázquez	Universidad de Cordoba
Jesús M. Zamarreño	University of Valladolid

Revisores Adicionales

Al-Kaff, Abdulla

Balbastre, Patricia
Beltrán de La Cita, Jorge
Bermudez-Cameo, Jesus
Blanco-Claraco, Jose-Luis
Blanes, Francisco
Bonin-Font, Francisco

Cancela, Brais

Ferraz, Luis

Garita, Cesar
Gimenez, Antonio
Gruber, Patrick
Guindel, Carlos

Hernandez Ruiz, Alejandro
Hernandez, Daniel

Jardón Huete, Alberto

López, Amable

Marin, Raul
Marín Plaza, Pablo
Mañanas, Miguel Angel
Morales, Rafael
Moreno, Francisco-Angel

Nuñez, Luis Ramón

Ponz Vila, Aurelio
Posadas-Yague, Juan-Luis
Poza-Luján, Jose-Luis
Pumarola, Albert

Raya, Rafael
Revestido Herrero, Elías
Rocon, Eduardo
Ruiz Sarmiento, José Raúl
Ruiz, Adria

Torres, Jose Luis

Vaquero, Victor

Table of Contents

Ingeniería de Control

TÚNEL DE AGUA PARA PRUEBAS Y CARACTERIZACIÓN DE DISEÑOS EXPERIMENTALES DE TURBINAS HIDROCINÉTICAS	1
<i>Eduardo Alvarez, Manuel Rico-Secades, Antonio Javier Calleja Rodríguez, Joaquín Fernández Francos, Aitor Fernández Jiménez, Mario Alvarez Fernández and Samuel Camba Fernández</i>	
Reduction of population variability in protein expression: A control engineering approach.	8
<i>Yadira Boada, Alejandro Vignoni and Jesús Picó</i>	
CONTROL ROBUSTO DEL PH EN FOTOBIORREACTORES MEDIANTE RECHAZO ACTIVO DE PERTURBACIONES	16
<i>José Carreño, Jose Luis Guzman, José Carlos Moreno and Rodolfo Villamizar</i>	
Control reset para maniobra de cambio de carril y validación con CarSim	23
<i>Miguel Cerdeira, Pablo Falcón, Antonio Barreiro, Emma Delgado and Miguel Díaz-Cacho</i>	
Maniobra de aterrizaje automática de una Cessna 172P modelada en FlightGear y controlada desde un programa en C	31
<i>Mario de La Rosa, Antonio Javier Gallego and Eduardo Fernández</i>	
Alternativas para el control de la red eléctrica aislada en parques eólicos marinos	38
<i>Carlos Díaz-Sanahuja, Ignacio Peñarrocha, Ricardo Vidal-Albalade and Ester Sales-Setién</i>	
CONTROL PREDICTIVO DISTRIBUIDO UTILIZANDO MODELOS DIFUSOS PARA LA NEGOCIACIÓN ENTRE AGENTES	46
<i>Lucía Fargallo, Silvana Roxani Revollar Chavez, Mario Francisco, Pastora Vega and Antonio Cembellín</i>	
Control Predictivo en el espacio de estados de un captador solar tipo Fresnel	54
<i>Antonio Javier Gallego, Mario de La Rosa and Eduardo Fernández</i>	
Control predictivo para la operación eficiente de una planta formada por un sistema de desalación solar y un invernadero	62
<i>Juan Diego Gil Vergel, Lidia Roca, Manuel Berenguel, Alba Ruiz Aguirre, Guillermo Zaragoza and Antonio Giménez</i>	
Depuración de Aguas Residuales en la Industria 4.0	70
<i>Jesus Manuel Gomez-De-Gabriel, Ana María Jiménez Arévalo, Laura Eiroa Mateo and Fco. Javier Fernández-De-Cañete-Rodríguez</i>	
Control robusto con QFT del pH en un fotobioreactor raceway	77
<i>Ángeles Hoyo Sánchez, Jose Luis Guzman, Jose Carlos Moreno and Manuel Berenguel</i>	
Revisión sistemática de la literatura en ingeniería de sistemas. Caso práctico: técnicas de estimación distribuida de sistemas ciberfísicos	84
<i>Carmelina Ierardi, Luis Orihuela Espina, Isabel Jurado Flores, Álvaro Rodríguez Del Nozal and Alejandro Tapia Córdoba</i>	
Desarrollo de un Controlador Predictivo para Autómatas programables basado en la normativa IEC 61131-3	92
<i>Pablo Krupa, Daniel Limon and Teodoro Alamo</i>	
Diseño de un emulador de aerogenerador de velocidad variable DFIG y control de pitch ...	100
<i>Manuel Lara Ortiz, Juan Garrido Jurado and Francisco Vázquez Serrano</i>	

Observación de la fracción de agua líquida en pilas de combustible tipo PEM de cátodo abierto.....	108
<i>Julio Luna and Ramon Costa-Castelló</i>	
Control Predictivo Basado en Datos.....	115
<i>José María Manzano, Daniel Limón, Teodoro Álamo and Jan Peter Calliess</i>	
Control MPC basado en un modelo LTV para seguimiento de trayectoria con estabilidad garantizada.....	122
<i>Sara Mata, Asier Zubizarreta, Ione Nieva, Itziar Cabanes and Charles Pinto</i>	
Implementación y evaluación de controladores basados en eventos en la norma IEC-61499.	130
<i>Oscar Miguel-Escrig, Julio-Ariel Romero-Pérez and Esteban Querol-Dolz</i>	
AUTOMATIZACIÓN Y MONITORIZACIÓN DE UNA INSTALACIÓN DE ENSAYO DE MOTORES.....	138
<i>Alfonso Poncela Méndez, Miguel Ochoa Vega, Eduardo J. Moya de La Torre and F. Javier García Ruíz</i>	
OPTIMIZACIÓN Y CONTROL EN CASCADA DE TEMPERATURA DE RECINTO MEDIANTE SISTEMAS DE REFRIGERACIÓN.....	146
<i>David Rodríguez, José Enrique Alonso Alfaya, Guillermo Bejarano Pellicer and Manuel G. Ortega</i>	
Diseño LQ e implementación distribuida para la estimación de estado.....	154
<i>Álvaro Rodríguez Del Nozal, Luis Orihuela, Pablo Millán Gata, Carmelina Ierardi and Alejandro Tapia Córdoba</i>	
Estimación de fugas en un sistema industrial real mediante modelado por señales aditivas.	160
<i>Ester Sales-Setién, Ignacio Peñarrocha and David Tena</i>	
Advanced control based on MPC ideas for offshore hydrogen production.....	167
<i>Alvaro Serna, Fernando Tadeo and Julio. E Normey-Rico</i>	
Transfer function parameters estimation by symmetric send-on-delta sampling.....	174
<i>José Sánchez, María Guinaldo, Sebastián Dormido and Antonio Visioli</i>	
An Estimation Approach for Process Control based on Asymmetric Oscillations.....	181
<i>José Sánchez, María Guinaldo Losada, Sebastian Dormido, José Luis Fernández Marrón and Antonio Visioli</i>	
Robust PI controller for disturbance attenuation and its application for voltage regulation in islanded microgrid.....	189
<i>Ramon Vilanova, Carles Pedret and Orlando Arrieta</i>	
Infraestructura para explotación de datos de un simulador azucarero.....	197
<i>Jesús M. Zamarreño, Cristian Pablos, Alejandro Merino, L. Felipe Acebes and De Prada César</i>	
<hr/>	
Automar	
<hr/>	
INFRAESTRUCTURA PARA ESTUDIAR ADAPTABILIDAD Y TRANSPARENCIA EN EL CENTRO DE CONTROL VERSÁTIL.....	203
<i>Juan Antonio Bonache Seco, José Antonio Lopez Orozco, Eva Besada Portas and Jesús Manuel de La Cruz</i>	
ARQUITECTURA DE CONTROL HÍBRIDA PARA LA NAVEGACIÓN DE VEHÍCULOS SUBMARINOS NO TRIPULADOS.....	211
<i>Francisco J. Lastra, Jesús A. Trujillo, Francisco J. Velasco and Elías Revestido</i>	

Exploración y Reconstrucción 3D de Fondos Marinos Mediante AUVs y Sensores Acústicos	218
<i>Oscar L. Manrique Garcia, Mario Andrei Garzon Oviedo and Antonio Barrientos</i>	
AUTOMATIZACIÓN DE MANIOBRAS PARA UN TEC DE 2GdL	226
<i>Marina Pérez de La Portilla, José Andrés Somolinos Sánchez, Amable López Piñeiro, Rafael Morales Herrera and Eva Segura</i>	
MERBOTS PROJECT: OVERALL DESCRIPTION, MULTISENSORY AUTONOMOUS PERCEPTION AND GRASPING FOR UNDERWATER ROBOTICS INTERVENTIONS	232
<i>Pedro J. Sanz, Raul Marin, Antonio Peñalver, David Fornas and Diego Centelles</i>	
<hr/> Bioingeniería <hr/>	
MARCADORES CUADRADOS Y DEFORMACIÓN DE OBJETOS EN NAVEGACIÓN QUIRÚRGICA CON REALIDAD AUMENTADA	238
<i>Eliana Aguilar, Oscar Andres Vivas and Jose Maria Sabater-Navarro</i>	
Entrenamiento robótico de la marcha en pacientes con Parálisis Cerebral: definición de objetivos, propuesta de tratamiento e implementación clínica preliminar	244
<i>Cristina Bayón, Teresa Martín-Lorenzo, Beatriz Moral-Saiz, Óscar Ramírez, Álvaro Pérez-Somarriba, Sergio Lerma-Lara, Ignacio Martínez and Eduardo Rocon</i>	
PREDICCIÓN DE ACTIVIDADES DE LA VIDA DIARIA EN ENTORNOS INTELIGENTES PARA PERSONAS CON MOVILIDAD REDUCIDA	251
<i>Arturo Bertomeu-Motos, Santiago Ezquerro, Juan Antonio Barios, Luis Daniel Lledó, Francisco Javier Badesa and Nicolas Garcia-Aracil</i>	
Sistema de Visión Estereoscópico para el guiado de un Robot Quirúrgico en Operaciones de Cirugía Laparoscópica HALS.....	256
<i>Carlos Castedo Hernández, Rafael Estop Remacha, Eusebio de La Fuente López and Lidia Santos Del Blanco</i>	
Head movement assessment of cerebral palsy users with severe motor disorders when they control a computer thought eye movements.....	264
<i>Alejandro Clemotte, Miguel A. Velasco and Eduardo Rocon</i>	
Diseño de un sensor óptico de fuerza para exoesqueletos de mano.....	270
<i>Jorge Diez Pomares, Andrea Blanco Ivorra, José María Catalan Orts, Francisco Javier Badesa Clemente, José María Sabater and Nicolas Garcia Aracil</i>	
POSIBILIDADES DEL USO DE TRAMAS ARTIFICIALES DE IMAGEN MOTORA PARA UN BCI BASADO EN EEG	276
<i>Josep Dinarès-Ferran, Christoph Guger and Jordi Solé-Casals</i>	
EFFECTOS SOBRE LA ERD EN TAREAS DE CONTROL DE EXOESQUELETO DE MANO EMPLEANDO BCI.....	282
<i>Santiago Ezquerro, Juan Antonio Barios, Arturo Bertomeu-Motos, Luisa Lorente, Nuria Requena, Irene Delegido, Francisco Javier Badesa and Nicolas Garcia-Aracil</i>	
Formulación Topológica Adaptada para la Simulación y Control de Exoesqueletos Accionados con Transmisiones Harmonic Drive.....	288
<i>Andres Hidalgo Romero and Eduardo Rocon</i>	

Identificación de contracciones isométricas de la extremidad superior en pacientes con lesión medular incompleta mediante características espectrales de la electromiografía de alta densidad (HD-EMG)	296
<i>Mislav Jordanic, Mónica Rojas-Martínez, Joan Francesc Alonso, Carolina Migliorelli and Miguel Ángel Mañanas</i>	
Diseño de una plataforma para analizar el efecto de la estimulación mecánica aferente en el temblor de pacientes con temblor esencial	302
<i>Julio S. Lora, Roberto López, Jesús González de La Aleja and Eduardo Rocon</i>	
DEFINICIÓN DE UN PROTOCOLO PARA LA MEDIDA PRECISA DEL RANGO CERVICAL EMPLEANDO TECNOLOGÍA INERCIAL	308
<i>Álvaro Martín, Rafael Raya, Cristina Sánchez, Rodrigo Garcia-Carmona, Oscar Ramirez and Abraham Otero</i>	
SISTEMA BRAIN-COMPUTER INTEFACE DE NAVEGACIÓN WEB ORIENTADO A PERSONAS CON GRAVE DISCAPACIDAD.....	313
<i>Víctor Martínez-Cagigal, Javier Gómez-Pilar, Daniel Álvarez, Eduardo Santamaría-Vázquez and Roberto Hornero</i>	
ESTRATEGIAS DE NEUROESTIMULACIÓN TRANSCRANEAL POR CORRIENTE DIRECTA PARA MEJORA COGNITIVA	320
<i>Silvia Moreno Serrano, Mario Ortiz and José María Azorín Poveda</i>	
COMPARATIVA DE ALGORITMOS PARA LA DETECCIÓN ONLINE DE IMAGINACIÓN MOTORA DE LA MARCHA BASADO EN SEÑALES DE EEG	328
<i>Marisol Rodriguez-Ugarte, Irma Nayeli Angulo Sherman, Eduardo Iáñez and Jose M. Azorin</i>	
DETECCIÓN, MEDIANTE UN GUANTE SENSORIZADO, DE MOVIMIENTOS SELECCIONADOS EN UN SISTEMA ROBOTIZADO COLABORATIVO PARA HALS	334
<i>Lidia Santos, José Luis González, Eusebio de La Fuente, Juan Carlos Fraile and Javier Pérez Turiel</i>	
BIOSENSORES PARA CONTROL Y SEGUIMIENTO PATOLOGÍAS REUMATOIDES	340
<i>Amparo Tirado, Raúl Marín, José V Martí, Miguel Belmonte and Pedro Sanz</i>	
Assessment of tremor severity in patients with essential tremor using smartwatches	347
<i>Miguel A. Velasco, Roberto López-Blanco, Juan P. Romero, M. Dolores Del Castillo, J. Ignacio Serrano, Julián Benito-León and Eduardo Rocon</i>	
INTERFAZ CEREBRO-ORDENADOR PARA EL CONTROL DE UNA SILLA DE RUEDAS A TRAVÉS DE DOS PARADIGMAS DE NAVEGACIÓN	353
<i>Fernández-Rodríguez Álvaro, Velasco-Álvarez Francisco and Ricardo Ron-Angevin</i>	
<hr/>	
Control Inteligente	
<hr/>	
Aprendizaje por Refuerzo para sistemas lineales discretos con dinámica desconocida: Simulación y Aplicación a un Sistema Electromecánico	360
<i>Henry Diaz, Antonio Sala and Leopoldo Armesto</i>	
Diseño de sistemas de control en cascada clásico y borroso para el seguimiento de trayectorias	368
<i>Javier G. Gonzalez, Rodolfo Haber, Fernando Matia and Marcelino Novo</i>	

ANÁLISIS FORMAL DE LA DINÁMICA DE SISTEMAS NO LINEALES MEDIANTE REDES NEURONALES.....	376
<i>Eloy Irigoyen, Mikel Larrea, A. Javier Barragán, Miguel Ángel Martínez and José Manuel Andújar</i>	
Predicción de la energía renovable proveniente del oleaje en las islas de Fuerteventura y Lanzarote.	384
<i>G.Nicolás Marichal, Deivis Avila, Ángela Hernández, Isidro Padrón and José Ángel Rodríguez</i>	
Aplicación de Redes Neuronales para la Estimación de la Resistencia al Avance en Buques	393
<i>Daniel Marón Blanco and Matilde Santos</i>	
Novel Fuzzy Torque Vectoring Controller for Electric Vehicles with per-wheel Motors	401
<i>Alberto Parra, Martín Dendaluze, Asier Zubizarreta and Joshué Pérez</i>	
REPOSTAJE EN TIERRA DE UN AVIÓN MEDIANTE ALGORITMOS GENÉTICOS .	408
<i>Elías Plaza and Matilde Santos</i>	
VISUALIZACIÓN WEB INTERACTIVA PARA EL ANÁLISIS DEL CHATTER EN LAMINACIÓN EN FRÍO.....	416
<i>Daniel Pérez López, Abel Alberto Cuadrado Vega and Ignacio Díaz Blanco</i>	
BANCADA PARA ANÁLISIS INTELIGENTE DE DATOS EN MONITORIZACIÓN DE SALUD ESTRUCTURAL.....	424
<i>Daniel Pérez López, Diego García Pérez, Ignacio Díaz Blanco and Abel Alberto Cuadrado Vega</i>	
CONTROL DE UN VEHÍCULO CUATRIRROTOR BASADO EN REDES NEURONALES.....	431
<i>Jesus Enrique Sierra and Matilde Santos</i>	
CONTROL PREDICTIVO FUZZY CON APLICACIÓN A LA DEPURACIÓN BIOLÓGICA DE FANGOS ACTIVADOS.....	437
<i>Pedro M. Vallejo Llamas and Pastora Vega Cruz</i>	
<hr/> Educación en Automática <hr/>	
REFLEXIONES SOBRE EL VALOR DOCENTE DE UNA COMPETICION DE DRONES EN LA EDUCACIÓN PARA EL CONTROL.....	445
<i>Ignacio Díaz Blanco, Alvaro Escanciano Urigüen, Antonio Robles Alvarez and Hilario López García</i>	
Uso del Haptic Paddle con aprendizaje basado en proyectos	451
<i>Juan M. Gandarias, Antonio José Muñoz-Ramírez and Jesus Manuel Gomez-De-Gabriel</i>	
REPRESENTACION INTEGRADA DE ACCIONAMIENTOS MECANICOS Y CONTROL DE EJES ORIENTADA A LA COMUNICACIÓN Y DOCENCIA EN MECATRONICA	457
<i>Julio Garrido Campos, David Santos Esterán, Juan Sáez López and José Ignacio Armesto Quiroga</i>	
Construcción y modelado de un prototipo fan & plate para prácticas de control automático	465
<i>Cristina Lampon, Javier Martin, Ramon Costa-Castelló and Muppaneni Lokesh Chowdary</i>	

EDUCACION EN AUTOMATICA E INDUSTRIA 4.0 MEDIANTE LA APLICACIÓN DE TECNOLOGÍAS 3D	471
<i>Jose Ramon Llata, Esther Gonzalez-Sarabia, Carlos Torre-Ferrero and Ramon Sancibrian</i>	
Desarrollo e implementación de un sistema de control en una planta piloto hibrida.....	479
<i>Maria P. Marcos, Cesar de Prada and Jose Luis Pitarch</i>	
LA INFORMÁTICA INDUSTRIAL EN LAS INGENIERÍAS INDUSTRIALES	486
<i>Rogelio Mazaeda, Eusebio de La Fuente López, José Luis González, Eduardo J. Moya de La Torre, Miguel Angel García Blanco, Javier García Ruiz, María Jesús de La Fuente Aparicio, Gregorio Sainz Palmero and Smaranda Cristea</i>	
Ventajas docentes de un flotador magnético para la experimentación de técnicas control ..	495
<i>Eduardo Montijano, Carlos Bernal, Carlos Sagües, Antonio Bono and Jesús Sergio Artal</i>	
PROGRAMACIÓN ATRACTIVA DE PLC	502
<i>Eduardo J. Moya de La Torre, F. Javier García Ruíz, Alfonso Poncela Méndez and Victor Barrio Lángara</i>	
MODERNIZACIÓN DE EQUIPO FEEDBACK MS-150 PARA EL APRENDIZAJE ACTIVO EN INGENIERÍA DE CONTROL	510
<i>Perfecto Reguera Acevedo, Miguel Ángel Prada Medrano, Antonio Morán Álvarez, Juan José Fuertes Martínez, Manuel Domínguez González and Serafín Alonso Castro</i>	
INNOVACIÓN PEDAGÓGICA EN LA FORMACIÓN DEL PERFIL PROFESIONAL PARA EL DESARROLLO DE PROYECTOS DE AUTOMATIZACIÓN INDUSTRIAL A TRAVÉS DE UNA APROXIMACIÓN HOLÍSTICA.	517
<i>Juan Carlos Ríos, Zaneta Babel, Daniel Martínez, José María Paredes, Luis Alonso, Pablo Hernández, Alejandro García, David Álvarez, Jorge Miranda, Constantino Manuel Valdés and Jesús Alonso</i>	
Aprendiendo Simulación de Eventos Discretos con JaamSim	522
<i>Enrique Teruel and Rosario Aragüés</i>	
RED NEURONAL AUTORREGRESIVA NO LINEAL CON ENTRADAS EXÓGENAS PARA LA PREDICCIÓN DEL ELECTROENCEFALOGRAMA FETAL...	528
<i>Rosa M Aguilar, Jesús Torres and Carlos Martín</i>	
ANÁLISIS DEL COEFICIENTE DE TRANSFERENCIA DE MATERIA EN REACTORES RACEWAYS.....	534
<i>Marta Barceló, Jose Luis Guzman, Francisco Gabriel Acién, Ismael Martín and Jorge Antonio Sánchez</i>	
MODELADO DINÁMICO DE UN SISTEMA DE ALMACENAMIENTO DE FRÍO VINCULADO A UN CICLO DE REFRIGERACIÓN	539
<i>Guillermo Bejarano Pellicer, José Joaquín Suffo, Manuel Vargas and Manuel G. Ortega</i>	
Predictor Intervalar basado en hiperplano soporte	547
<i>José Manuel Bravo Caro, Manuel Vasallo Vázquez, Emilian Cojocarú and Teodoro Alamo Cantarero</i>	
Dynamic simulation applied to refinery hydrogen networks	555
<i>Anibal Galan Prado, Cesar De Prada, Gloria Gutierrez, Rafael Gonzalez and Daniel Sarabia</i>	

APROXIMACIÓN DE MODELOS ALGEBRAICOS MEDIANTE ALAMO Y ECOSIMPRO	563
<i>Carlos Gómez Palacín, José Luis Pitarch, Gloria Gutiérrez and Cesar De Prada</i>	
A Causal Model to Analyze Aircraft Collision Avoidance Deadlock Scenarios	569
<i>Miquel Àngel Piera Eroles, Julia de Homdedeu, Maria Del Mar Tous, Thimjo Koca and Marko Radanovic</i>	
ONLINE DECISION SUPPORT FOR AN EVAPORATION NETWORK	575
<i>José Luis Pitarch, Marc Kalliski, Carlos Gómez Palacín, Christian Jasch and Cesar De Prada</i>	
Predicción de la irradiancia a partir de datos de satélite mediante deep learning	582
<i>Javier Pérez, Jorge Segarra-Tamarit, Hector Beltran, Carlos Ariño, José Carlos Alfonso Gil, Aleks Attanasio and Emilio Pérez</i>	
MODELO DINÁMICO ORIENTADO AL TRATAMIENTO Y SEGUIMIENTO DE LA LEUCEMIA MIELOIDE CRÓNICA	589
<i>Gabriel Pérez Rodríguez and Fernando Morilla</i>	
Modelado y optimización de la operación de un sistema de bombeo de múltiples depósitos	596
<i>Roberto Sanchis Llopis and Ignacio Peñarrocha</i>	
DEVELOPMENT OF A GREY MODEL FOR A MEDIUM DENSITY FIBREBOARD DRYER IN ECOSIMPRO	604
<i>Pedro Santos, Jose Luis Pitarch and César de Prada</i>	
DETECCIÓN AUTOMÁTICA DE FALLOS MEDIANTE MONITORIZACIÓN Y OPTIMIZACIÓN DE LAS FECHAS DE LIMPIEZA PARA INSTALACIONES FOTOVOLTAICAS	611
<i>Jorge Segarra-Tamarit, Emilio Pérez, Hector Beltran, Enrique Belenguer and José Luis Gandía</i>	
Modelado de micro-central hidráulica para el diseño de controladores con aplicación en regiones aisladas de Honduras	618
<i>Alejandro Tapia Córdoba, Pablo Millán Gata, Fabio Gómez-Estern Aguilar, Carmelina Ierardi and Álvaro Rodríguez Del Nozal</i>	
FRAMEWORK PARA EL MODELADO DE UN LAGO DE DATOS	626
<i>J.M Torres, R.M. Aguilar, C.A. Martin and S. Diaz</i>	
SIMULADOR CARDIOVASCULAR PARA ENSAYO DE ROBOTS DE NAVEGACION AUTONOMA	633
<i>José Emilio Traver, Juan Francisco Ortega Morán, Ines Tejado, J. Blas Pagador, Fei Sun, Raquel Pérez-Aloe, Blas M. Vinagre and F. Miguel Sánchez Margallo</i>	
PLANIFICACION DE LA PRODUCCION BASADA EN CONTROL PREDICTIVO PARA PLANTAS TERMOSOLARES	641
<i>Manuel Jesús Vasallo Vázquez, José Manuel Bravo Caro, Emilian Cojocarú and Manuel Emilio Gegundez Arias</i>	
Evaluación multicriterio para la optimización de redes de energía	649
<i>Ascensión Zafra Cabeza, Rafael Espinosa, Miguel Àngel Ridao Carlini and Carlos Bordóns Alba</i>	
Percibiendo el entorno en los robots sociales del RoboticsLab	657
<i>Fernando Alonso Martín, Jose Carlos Castillo Montoya, Àlvaro Castro-Gonzalez, Juan José Gamboa, Marcos Maroto Gómez, Sara Marqués Villaroya, Antonio J. Pérez Vidal and Miguel Àngel Salichs</i>	

DISEÑO DE UNA PRÓTESIS DE MANO ADAPTABLE AL CRECIMIENTO	664
<i>Marta Ayats and Raul Suarez</i>	
COOPERATIVISMO BIOINSPIRADO BASADO EN EL COMPORTAMIENTO DE LAS HORMIGAS	672
<i>Brayan Bermudez, Kristel Novoa and Miguel Valbuena</i>	
PROCEDIMIENTO DE DISEÑO DE UN EXOESQUELETO DE MIEMBRO SUPERIOR PARA SOPORTE DE CARGAS	680
<i>Andrea Blanco Ivorra, Jorge Diez Pomares, David Lopez Perez, Francisco Javier Badesa Clemente, Miguel Ignacio Sanchez and Nicolas Garcia Aracil</i>	
Estructura de control en ROS y modos de marcha basados en máquinas de estados de un robot hexápodo	686
<i>Raúl Cebolla Arroyo, Jorge De Leon Rivas and Antonio Barrientos</i>	
USING AN UAV TO GUIDE THE TELEOPERATION OF A MOBILE MANIPULATOR	694
<i>Josep Arnau Claret and Luis Basañez</i>	
Estudio de los patrones de marcha para un robot hexápodo en tareas de búsqueda y rescate	701
<i>Jorge De León Rivas and Antonio Barrientos</i>	
SISTEMA DE INTERACCIÓN VISUAL PARA UN ROBOT SOCIAL	709
<i>Mario Domínguez López, Eduardo Zalama Casanova, Jaime Gómez García-Bermejo and Samuel Marcos Pablos</i>	
Mejora del Comportamiento Proxémico de un Robot Autónomo mediante Motores de Inteligencia Artificial Desarrollados para Plataformas de Videojuegos	717
<i>David Fernández Chaves, Javier Monroy and Javier Gonzalez-Jimenez</i>	
Micrófonos de contacto: una alternativa para sensado táctil en robots sociales	724
<i>Juan José Gamboa, Fernando Alonso Martín, Jose Carlos Castillo, Marcos Maroto Gómez and Miguel A. Salichs</i>	
Clasificación de información táctil para la detección de personas	732
<i>Juan M. Gandarias, Jesús M. Gómez-De-Gabriel and Alfonso García-Cerezo</i>	
Planificación para interceptación de objetivos: Integración del Método Fast Marching y Risk-RRT	738
<i>David Alfredo Garzon Ramos, Mario Andrei Garzon Oviedo and Antonio Barrientos</i>	
ESTABILIZACIÓN DE UNA BOLA SOBRE UN PLANO UTILIZANDO UN ROBOT PARALELO 6-RSS	746
<i>Daniel González, Lluís Ros and Federico Thomas</i>	
TELEOPERACIÓN DE INSTRUMENTOS QUIRÚRGICOS ARTICULADOS	754
<i>Ana Gómez Delgado, Carlos Perez-Del-Pulgar, Antonio Reina Terol and Victor Muñoz Martinez</i>	
CONTROL OF A ROBOTIC ARM FOR TRANSPORTING OBJECTS BASED ON NEURO-FUZZY LEARNING VISUAL INFORMATION	760
<i>Juan Hernández Vicén, Santiago Martínez de La Casa Díaz and Carlos Balaguer</i>	
PLATAFORMA BASADA EN LA INTEGRACIÓN DE MATLAB Y ROS PARA LA DOCENCIA DE ROBÓTICA DE SERVICIO	766
<i>Carlos G. Juan, Jose Maria Vicente, Alvaro Garcia and Jose Maria Sabater-Navarro</i>	

Estimadores de fuerza y movimiento para el control de un robot de rehabilitación de extremidad superior.....	772
<i>Aitziber Mancisidor, Asier Zubizarreta, Itziar Cabanes, Pablo Bengoa and Asier Brull</i>	
Definiendo los elementos que constituyen un robot social portable de bajo coste	780
<i>Marcos Maroto Gómez, José Carlos Castillo, Fernando Alonso-Martín, Juan José Gamboa, Sara Marqués Villarroya and Miguel Ángel Salichs</i>	
Interfaces táctiles para Interacción Humano-Robot	787
<i>Sara Marqués Villarroya, Jose Carlos Castillo Montoya, Fernando Alonso Martín, Marcos Maroto Gómez, Juan José Gamboa and Miguel A. Salichs</i>	
HERRAMIENTAS DE ENTRENAMIENTO Y MONITORIZACIÓN PARA EL DESMINADO HUMANITARIO	793
<i>Hector Montes, Roemi Fernandez, Pablo Gonzalez de Santos and Manuel Armada</i>	
Control a Baja Velocidad de una Rueda con Motor de Accionamiento Directo mediante Ingeniería Basada en Modelos	799
<i>Antonio José Muñoz-Ramírez, Jesús Manuel Luque-Bedmar, Jesus Manuel Gomez-De-Gabriel, Anthony Mandow, Javier Serón and Alfonso Garcia-Cerezo</i>	
SIMULACIÓN DE VEHÍCULOS AUTÓNOMOS USANDO V-REP BAJO ROS	806
<i>Cándido Otero Moreira, Enrique Paz Domonte, Rafael Sanz Dominguez, Joaquín López Fernández, Rafael Barea, Eduardo Romera, Eduardo Molinos, Roberto Arroyo, Luís Miguel Bergasa and Elena López</i>	
Cinemática y prototipado de un manipulador paralelo con centro de rotación remoto para robótica quirúrgica.....	814
<i>Francisco Pastor, Juan M. Gandarias and Jesús M. Gómez-De-Gabriel</i>	
ANÁLISIS DE ESTABILIDAD DE SINGULARIDADES AISLADAS EN ROBOTS PARALELOS MEDIANTE DESARROLLOS DE TAYLOR DE SEGUNDO ORDEN.....	821
<i>Adrián Peidro Vidal, Óscar Reinoso, Arturo Gil, José María Marín and Luis Payá</i>	
INTERFAZ DE CONTROL PARA UN ROBOT MANIPULADOR MEDIANTE REALIDAD VIRTUAL	829
<i>Elena Peña-Tapia, Juan Jesús Roldán, Mario Garzón, Andrés Martín-Barrio and Antonio Barrientos</i>	
Evolución de la robótica social y nuevas tendencias	836
<i>Antonio J. Pérez Vidal, Alvaro Castro-Gonzalez, Fernando Alonso Martín, Jose Carlos Castillo Montoya and Miguel A. Salichs</i>	
DISEÑO MECÁNICO DE UN ASISTENTE ROBÓTICO CAMARÓGRAFO CON APRENDIZAJE COGNITIVO	844
<i>Irene Rivas-Blanco, M Carmen López-Casado, Carlos Pérez-Del-Pulgar, Francisco García-Vacas, Víctor Fernando Muñoz, Enrique Bauzano and Juan Carlos Fraile</i>	
CÁLCULO DE FUERZAS DE CONTACTO PARA PRENSIONES BIMANUALES.....	852
<i>Francisco Abiud Rojas-De-Silva and Raul Suarez</i>	
Modelado del Contexto Geométrico para el Reconocimiento de Objetos.....	860
<i>José Raúl Ruiz Sarmiento, Cipriano Galindo and Javier Gonzalez-Jimenez</i>	
Estimación Probabilística de Áreas de Emisión de Gases con un Robot Móvil Mediante la Integración Temporal de Observaciones de Gas y Viento	868
<i>Carlos Sanchez-Garrido, Javier Monroy and Javier Gonzalez-Jimenez</i>	

MANIPULADOR AÉREO CON BRAZOS ANTROPOMÓRFICOS DE ARTICULACIONES FLEXIBLES	876
<i>Alejandro Suarez, Guillermo Heredia and Anibal Ollero</i>	
EVALUACIÓN DE UN ENTORNO DE TELEOPERACIÓN CON ROS	864
<i>David Vargas Frutos, Juan Carlos Ramos Martínez, José Luis Samper Escudero, Miguel Ángel Sánchez-Urán González and Manuel Ferre Pérez</i>	

Sistemas de Tiempo Real

GENERACIÓN DE CÓDIGO IEC 61131-3 A PARTIR DE DISEÑOS EN GRAFCET....	892
<i>María Luz Alvarez Gutierrez, Isabel Sarachaga Gonzalez, Arantzazu Burgos Fernandez, Nagore Iriondo Urbistazu and Marga Marcos Muñoz</i>	
CONTROL EN TIEMPO REAL Y SUPERVISIÓN DE PROCESOS MEDIANTE SERVIDORES OPC-UA	900
<i>Francisco Blanes Noguera and Andrés Benlloch Faus</i>	
Control de la Ejecución en Sistemas de Criticidad Mixta	906
<i>Alfons Crespo, Patricia Balbastre, Jose Simo and Javier Coronel</i>	
GENERACIÓN AUTOMÁTICA DEL PROYECTO DE AUTOMATIZACIÓN TIA PORTAL PARA MÁQUINAS MODULARES	913
<i>Darío Orive, Aintzane Armentia, Eneko Fernandez and Marga Marcos</i>	
DDS en el desarrollo de sistemas distribuidos heterogéneos con soporte para criticidad mixta	921
<i>Hector Perez and J. Javier Gutiérrez</i>	
ARQUITECTURA DISTRIBUIDA PARA EL CONTROL AUTÓNOMO DE DRONES EN INTERIOR	929
<i>Jose-Luis Poza-Luján, Juan-Luis Posadas-Yaguë, Giovanni-Javier Tipantuña-Topanta, Francisco Abad and Ramón Mollá</i>	
Ingeniería Conducida por Modelos en Sistemas de Automatización Flexibles	935
<i>Rafael Priego, Elisabet Estévez, Darío Orive, Isabel Sarachaga and Marga Marcos</i>	
Estudio e implementación de Middleware para aplicaciones de control distribuido	942
<i>Jose Simo, Jose-Luis Poza-Lujan, Juan-Luis Posadas-Yaguë and Francisco Blanes</i>	

Visión por Computador

Real-Time Image Mosaicking for Mapping and Exploration Purposes	948
<i>Abdulla Al-Kaff, Juan Camilo Soto Triviño, Raúl Sosa San Frutos, Arturo de La Escalera and José María Armingol Moreno</i>	
ALGORITMO DE SLAM UTILIZANDO APARIENCIA GLOBAL DE IMÁGENES OMNIDIRECCIONALES	956
<i>Yerai Berenguer, Luis Payá, Mónica Ballesta, Luis Miguel Jiménez, Sergio Cebollada and Oscar Reinoso</i>	
Medición de Oximetría de Pulso mediante Imagen fotopletismográfica.....	964
<i>Juan-Carlos Cobos-Torres, Jordan Ortega Rodríguez, Pablo J. Alhama Blanco and Mohamed Abderrahim</i>	
Algoritmo de captura de movimiento basado en visión por computador para la teleoperación de robots humanoides	970
<i>Juan Miguel Garcia Haro and Santiago Martinez de La Casa</i>	

COMPARACIÓN DE MÉTODOS DE DETECCIÓN DE ROSTROS EN IMÁGENES DIGITALES	976
<i>Natalia García Del Prado, Victor Gonzalez Castro, Enrique Alegre and Eduardo Fidalgo Fernández</i>	
LOCALIZACIÓN DEL PUNTO DE FUGA PARA SISTEMA DE DETECCIÓN DE LÍNEAS DE CARRIL	983
<i>Manuel Ibarra-Arenado, Tardi Tjahjadi, Sandra Robla-Gómez and Juan Pérez-Oria</i>	
Oculus-Crawl, a Software Tool for Building Datasets for Computer Vision Tasks	991
<i>Iván De Paz Centeno, Eduardo Fidalgo Fernández, Enrique Alegre Gutiérrez and Wesam Al Nabki</i>	
Clasificación automática de obstáculos empleando escáner láser y visión por computador ..	999
<i>Aurelio Ponz, Fernando Garcia, David Martin, Arturo de La Escalera and Jose Maria Armingol</i>	
T-SCAN: OBTENCIÓN DE NUBES DE PUNTOS CON COLOR Y TEMPERATURA EN INTERIOR DE EDIFICIOS	1007
<i>Tomás Prado, Blanca Quintana, Samuel A. Prieto and Antonio Adan</i>	
EVALUACIÓN DE MÉTODOS PARA REALIZAR RESÚMENES AUTOMÁTICOS DE VÍDEOS	1015
<i>Pablo Rubio, Eduardo Fidalgo, Enrique Alegre and Víctor González</i>	
SIMULADOR PARA LA CREACIÓN DE MUNDOS VIRTUALES PARA LA ASISTENCIA A PERSONAS CON MOVILIDAD REDUCIDA EN SILLA DE RUEDAS .	1023
<i>Carlos Sánchez Sánchez, María Cidoncha Jiménez, Emiliano Pérez, Ines Tejado and Blas M. Vinagre</i>	
Calibración Extrínseca de un Conjunto de Cámaras RGB-D sobre un Robot Móvil	1031
<i>David Zúñiga-Nöel, Rubén Gómez Ojeda, Francisco-Ángel Moreno and Javier González Jiménez</i>	

Robust PI controller for disturbance attenuation and its application for voltage regulation in islanded microgrid

R. Vilanova (Ramon.Vilanova@uab.cat), Carles Pedret (Carles.Pedret@uab.cat)
School of Engineering. Universitat Autònoma de Barcelona. , Barcelona, Spain

Orlando Arrieta (ORLANDO.ARRIETA@ucr.ac.cr) School of Electrical Engineering,
University of Costa Rica, 11501-2060 San Jose, Costa Rica.

Resumen

This work faces the problem of frequency deviation in microgrid systems. The considered microgrid includes renewable energy sources such as wind and solar photovoltaic. As long as these sources provide an irregular power supply or there is a sudden change in the system load, the power system frequency deviates. In order to compensate such deviations, alternative, conventional energy sources should be commanded in order to provide the corresponding power deficit. In this paper a very simple and of common industrial practice control approach such as the Direct synthesis based on first order plus time delay models is proposed to tune a PI controller. Time domain simulations show the effectiveness of the approach as compared with other more sophisticated controllers (Fractional order PID) already proposed in the literature.

Palabras clave: PI Control, Disturbance attenuation, Microgrid,

1 Introduction

A MicroGrid (MG) is a small scale grid that can integrate distributed renewable energy sources, conventional generators, energy storage systems and consumers. It can be operated in either grid-connected or islanded mode in case of grid faults or planned islanding. [1,2]. The MG embodies the concept of a single organized power subsystem comprising a number of distributed generation systems, both renewable (such as photovoltaic, wind power, hydro and fuel-cell devices) and/or conventional generation (such as internal combustion engines, micro-turbines and diesel generators) and a cluster of loads [1]. Some of the benefits of MG, including enhanced local reliability, reduced feeder loss, better local voltage support, increased efficiency, voltage sag correction or uninterruptible power supply function are also reviewed in [2, 3].

In recent years, emphasis has been placed on renewable energy based MG systems. In order to improve the efficiency of MGs and to reduce fossil fuel usage and pollution, renewable energy sources may be integrated with traditional MGs. Renewable energy sources include photovoltaic power, hydro power and wind power. These are clean and abundantly available energy sources. However as the power generation of such units is highly dependent of external environmental factors, the generated powers are subject to variations that can impact the MG supplied frequency and therefore the quality of the MG as a generation system. In order to facilitate to operate in islanded mode for extended periods with renewable energy sources involved, it is critical to maintain the frequency deviations within a small range in order to satisfy operating requirements.

Therefore, a reliable and stable operation of isolated hybrid renewable energy system is more complex, unlike those that are grid connected. The fluctuations in both wind speed and solar radiation lead to mismatch between the power generation and load demand resulting into deviation in system frequency and voltage from the nominal value. These undue disturbances if allowed to exceed beyond the tolerance limit may lead to undesired performance and result into damage of the connected devices/equipments.

As a result of the reported problem, different control methods have been proposed in the literature to tackle frequency deviations. Proportional-Integral-Derivative (PID) control has been well studied by a number of researchers [4], [5], [6]. H_{inf} control is considered in [7] and [8]. Recently, there has been some interest in the application of intelligent approaches such as those based on Fuzzy Logic control, as in [9], or evolutive optimization algorithms such as genetic algorithm based PID controllers [10], robust PSO-based H_{inf} [7], robust H_{∞} and μ -synthesis approaches [11]. The application of such advanced optimization methods has also been focused in the tuning of fractional order PID (FOPID) controllers. As an

example, the kriging based surrogate modeling method in [12] is used to design a FOPID controller, whereas in [13] a chaotic PSO based fractional order fuzzy PID controller is faced. In addition, [14] utilised a chaotic NSGA-II algorithm to design a FOPID.

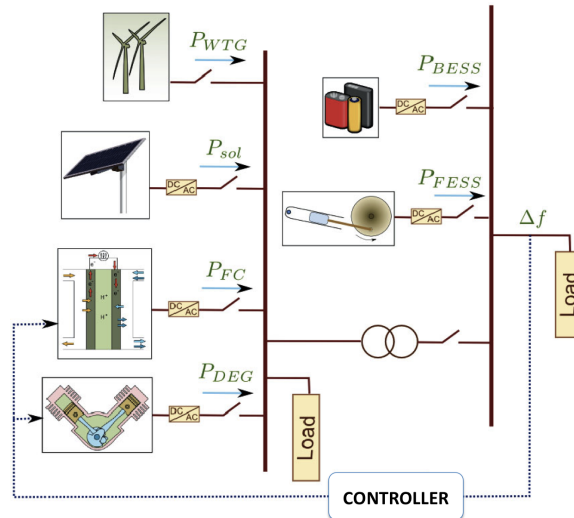
The main focus of the mentioned approaches is to regulate for frequency deviations. However, it is also important to account for control input usage. As the main task of the controller will be to push for conventional generation when power delivered by the renewable sources does not satisfy demand, this control signal will determine the requirement for extra fuel in the generation units. This need for more efficient control from the input usage, while maintaining frequency deviation within the required limits, is the main motivation for the application of simple control strategies that while achieving average frequency deviation within the desired levels, its tuning allows for an easy tradeoff between accuracy and control input usage. This input usage will directly translate from smooth to high frequency power demand generation.

The controller that is proposed in this paper is a simple PI controller tuned on the basis of the Internal Model Control. One of the attractive features of the PI based IMC. This is a very straightforward approach, also well known from industrial practice. The controller design complexity is kept at a minimum. There will be no need for going through complex optimization approaches and, in addition, the process information will be as simple as a first order plus dead time model. As these models are usually employed in industry, jointly with IMC formulations, it is the authors opinion that this fact will definitely help system operators to gain confidence in the control scheme.

2 Micro Grid system description and modelling

A typical setup of a MG with storage system is shown in Figure 1. The energy sources include both conventional and renewable generation systems. This system can be easily extended to more complex MGs, with additional generators. However the main idea is to increase the usage of renewable energy, and so reduce the fossil fuel consumption, while at the same time maintaining system stability. Here system stability is reflected by incurring only limited system frequency deviations, despite the presence of significant transients. The MG system used in this work is based on the study presented in [15] and used in [12] to

derive a FOPID controller. The system includes various power generating units like the wind turbine, photovoltaic cell, fuel cells, and diesel energy generator. There is also a battery and a flywheel energy storage system. The dynamical models in



Figurea 1: Layout for the microgrid system considered in this work. [12]

Figure 1. are represented here as small signal linearized transfer functions which captures the dynamic characteristics at a specific operating point [15],[10]. Even with such simplifications, these models still capture the essential power/frequency tradeoffs present in a MG system. Since is caused by the imbalance between the power generated and the power consumed by the load, signals in the model are first normalized to per-unit (pu), and then shifted to deviations around 0 (corresponding to deviations from nominal 60 Hz [16]). The characterization of the renewable energy sources power as well as the load power demand follows the patterns presented in [10]. The established deterministic drifts are complemented here with stochastic power fluctuations. A general template that gives rise to a time-series with small stochastic fluctuations about the mean generated or demand power is used. The general template is chosen as:

$$P = \frac{\phi\nu\sqrt{\beta}(1 - G(s)) + \beta}{\beta}\Gamma = \chi\Gamma \quad (1)$$

where, P represents the power output of the solar, wind or the load model, ϕ is the stochastic component of the power, β contributes to the mean value of the power, $G(s)$ is a low pass filter, ν is a constant in order to normalize the generated or demand power (χ) to match the per unit (pu)

level, Γ is a time dependent switching signal with a gain which dictates the sudden fluctuation in mean value for the stochastic power output. Being $U(-1, 1)$ a random uniform distribution between -1 and 1, and $h(t)$ the unitary Heaviside step function, the parameters in (1) for each one of the three generators are given by:

Wind Power generation:

$$\phi \equiv U(-1, 1), \nu = 0.8, \beta = 10, G(s) = 1/(10^4 s + 1)$$

$$\Gamma = 0.24h(t) - 0.04h(t - 140)$$

Solar Power generation:

$$\phi \equiv U(-1, 1), \nu = 0.1, \beta = 10, G(s) = 1/(10^4 s + 1)$$

$$\Gamma = 0.05h(t) + 0.02h(t - 180).$$

Load Power demand:

$$\phi \equiv U(-1, 1), \nu = 0.9, \beta = 10$$

$$G(s) = 300/(300s + 1) + 1/(1800s + 1)$$

$$\Gamma = 0.02h(t) + (1/\chi)(0.9h(t) + 0.03h(t - 110) + 0.03h(t - 130) + 0.03h(t - 150) - 0.15h(t - 170) + 0.1h(t - 190))$$

For what matters to the small signal models for each one of the MG system components, they are given as in [15] and [12] by the following transfer functions and model parameters:

Wind turbine generator (WTG)

$$K_W = 1, T_W = 1.5 \text{sec and}$$

$$G_{WTG}(s) = \frac{\Delta P_{WTG}}{\Delta P_W} = \frac{K_W}{T_W s + 1}$$

Solar photovoltaic (PV) system

$$T_{IN} = 0.04 \text{sec}, T_{IC} = 0.004 \text{sec and}$$

$$G_{PV}(s) = \frac{\Delta P_{PV}}{\Delta P_{sol}} = \frac{1}{(T_{IN} s + 1)(T_{IC} s + 1)}$$

Diesel engine generator (DEG)

$$T_G = 0.08 \text{sec}, T_T = 0.4 \text{sec and}$$

$$G_{DEG}(s) = \frac{\Delta P_{DEG}}{\Delta u} = \frac{1}{(T_G s + 1)(T_T s + 1)}$$

Fuel cell (FC)

$$K_{FC} = 1, T_{FC} = 0.26 \text{sec and}$$

$$G_{FC}(s) = \frac{\Delta P_{FC}}{\Delta u} = \frac{K_{FC}}{(T_{FC} s + 1)(T_{IN} s + 1)(T_{IC} s + 1)}$$

Battery energy storage system (BESS)

$$K_{BESS} = 1, T_{BESS} = 0.1 \text{sec and}$$

$$G_{BESS}(s) = \frac{\Delta P_{BESS}}{\Delta f} = \frac{K_{BESS}}{T_{BESS} s + 1}$$

Flywheel energy storage system (FESS)

$$K_{FESS} = 1, T_{FESS} = 0.1 \text{sec and}$$

$$G_{FESS}(s) = \frac{\Delta P_{FESS}}{\Delta f} = \frac{K_{FESS}}{T_{FESS} s + 1}$$

Microgrid system

$D = 0.015 \text{pu/Hz}$, $H = 1/12 \text{pu.sec}$, $R = 3 \text{Hz/pu}$ and

$$G_{MGS}(s) = \frac{\Delta f}{\Delta P_e} = \frac{1}{2Hs + D}$$

For a more detailed description of the different units the interested reader is referred to [15] and [12]. Figure (2) provides the corresponding block diagram identifying the constitutive blocks of the MG system.

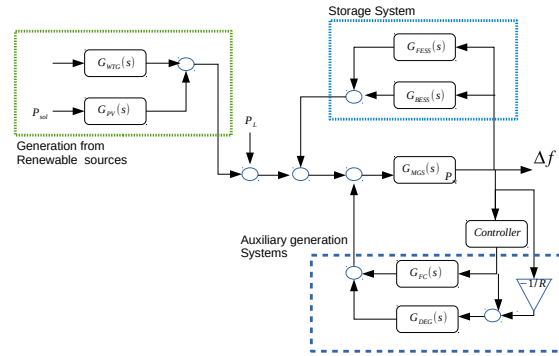


Figura 2: Block diagram for the considered microgrid.

3 Direct synthesis design (DS-d)

The Internal Model Control (IMC) approach for controller design as presented in [17] and further developed in [18] is based on the very basic principle of *close the loop when necessary*. One of the drawbacks of the IMC design is its poor response for load disturbance attenuation, specially when the system has slow time constants. Main reason for this is the fact that the plant dynamics appear in the disturbance to output response. In order to improve the regulation capabilities, some proposals have appeared in the literature. Widely referred works that concentrate

on tuning for improved disturbance rejection are, for example, [19, 20]. the direct synthesis (DS-d) method presented in [19] is perhaps the most generic one (it applies to a wide selection of process dynamics) for tuning of PI/PID controllers for input load disturbance attenuation.

The direct synthesis method is based on the specification of a desired y/d relation, denoted as $(y/d)_d$, and impose this relation for the regulatory closed-loop transfer function as:

$$C_y(s) = \frac{P_d(s)}{\left(\frac{y}{d}\right)_d P_u(s)} - \frac{1}{P_u(s)} \quad (2)$$

that simplifies to

$$C_y(s) = \frac{1}{\left(\frac{y}{d}\right)_d} - \frac{1}{P_u(s)} \quad (3)$$

when $P_d(s) = P_u(s)$. It is under this assumption and for a set of concrete dynamics for the process model transfer function $P_u(s)$, that in [19] tunings for the PI/PID controller parameters are suggested.

PI tuning relations

In fact, The DS-d method is presented as the disturbance counterpart to the more extended IMC that is based on specifying a tracking specification. For these two methods, the tuning relations that are provided for a PI controller applied to a first order plus time delay model are:

- *Process model:*

$$P_m(s) = \frac{K_m e^{-L_m s}}{T_m s + 1}$$

- *PI-IMC Tuning:*

$$K_p = \frac{T_m}{K_m(\lambda + L_m)} \quad T_i = T_m$$

- *PI-Load (DS-d) Tuning:*

$$K_p = \frac{2T_m - \lambda}{K_m \lambda} \quad T_i = \frac{(2T_m - \lambda)\lambda}{T_m}$$

4 Control problem definition

In this section the control goals that will be used to evaluate and to compare the different control approaches will be defined first. Second, we present the different controllers that will be applied to the MG scenario presented above. Two of the selected approaches are taken from recent literature results that are based on the same micro grid layout as the one presented here. Therefore more well suited for a fair comparison.

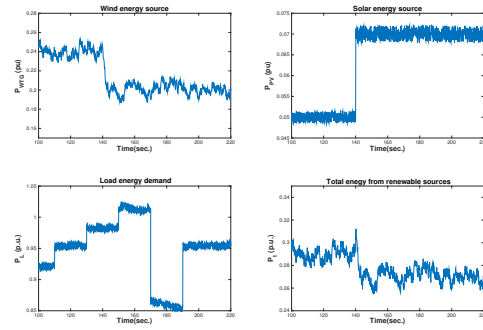


Figura 3: Stochastic realization for the wind and solar energy generation and power load demand

4.1 Control problem definition

As detailed when presenting the MG model, the power generation for the wind turbine generator, solar photovoltaic and the load are based on random functions. Figure 3 shows a single realization of the corresponding stochastic processes. As per the framework defined in [10] and [12], in the present work, it is considered that the MG was operating at 1 p.u. load during $0 < t < 100$ sec and the control system performance has been evaluated then for a finite time horizon of $100 < t < 220$ sec considering the changes in both the demand load and renewable generations shown in Figure 3. The primary goal of the control system is to maintain frequency fluctuation Δf at a minimum hence better power quality. Regarding the frequency deviation, as commented in [8], in general, for MGs, should be limited to within 1%, and the recovery time limited to couple of seconds. Otherwise most conventional breakers will trip, with the subsequent possibility of cascade effects. On that basis, we will take here a band of ± 0.005 that corresponds to a deviation of 0.5%. As a statistical measures will compute its mean $\mu(\Delta f)$ and standard deviation $\sigma(\Delta f)$.

In order to provide good quality of supply frequency can be maintained at the desired level by maintaining the active power balance between generation and demand. For such purpose, there is the need of a control system that compensates for the high fluctuations in renewable energy generators such as those based on wind and solar units. For such purpose the controller should provide the needed additional power. This is accomplished by sending the control signal to the fuel cell (FC) and the diesel energy generator (DEG) on the basis of the frequency deviation in the MG. The control signal, basically determines the supply for extra fuel on these units i.e., like the hydro-

gen flow rate in the FC and mass flow rate of oil in DEG. Regarding the flywheel and battery units, as in [9] their inputs are directly taken from the grid frequency oscillation signal without the intervention of the controller as these devices does not need sophisticated control.

Even the small signal models are transfer function based, saturation and rate limit constraints are used in order to constraint the extraction/storage of power. The output saturations (in pu) and rate constraints for the different energy storage and generation units are [12]:

$$|P_{FESS}| < 0.11, |P_{BESS}| < 0.11$$

$$0 < P_{FC} < 0.48, 0 < P_{DEG} < 0.45$$

$$|P_{FESS}| < 0.05, |P_{BESS}| < 0.05$$

$$|P_{FC}| < 1, |P_{DEG}| < 0.5$$

4.2 (FOPID) Fractional PID

In [12] the use of a fractional order PID (FOPID) controller for a MG is investigated. The transfer function representation for the considered FOPID controller is given by

$$C(s) = K_p + \frac{K_i}{s^\lambda} + K_d s^\nu \quad (4)$$

In [12], a global optimization approach is employed to obtain the five parameters of the FOPID controller. A kriging assisted surrogate modelling methodology is embedded within a global optimization framework for the design of the FOPID. As the models for the load and renewable energy sources are defined statistically, the evaluation of the cost function is stochastic. Therefore the function is evaluated multiple times and the expected value of the objective function is considered for optimization. The chosen cost function is a combined quadratic cost function that tradeoffs the frequency deviation and control usage:

$$J = \int_{t_{in}=100}^{t_{fi}=220} \left[\omega(\Delta f)^2 + \frac{(1-\omega)}{K_n}(\Delta u)^2 \right] dt \quad (5)$$

where, ω determines the relative importance of the two conflicting objectives and K_n is a normalizing constant. The values used in [12] are $\omega = 0.7$, $K_n = 10^4$. The resulting optimal values for the FOPID are

$$K_p = 0.950 \quad K_i = 4.350 \quad K_d = 1.250 \quad \lambda = 0.66 \quad \nu = 0.7 \quad (6)$$

In the same work, [12], it is shown that the FOPID provides superior performance over the integer order ideal controller. However, It has to be said

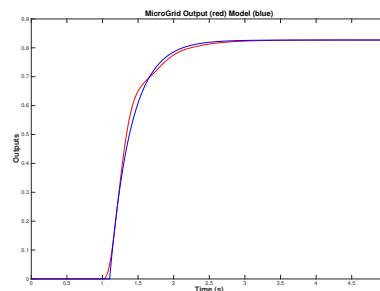


Figura 4: FOPTD model approximation for the MG system to the relation $\Delta f/\Delta u$

that both controllers, fractional and integer, are formulated as ideal controllers. Therefore, no derivative filters are mentioned. This may be a serious practical problem when using derivative action as any noise in the measurements will be transferred into the control signal. Another important point regarding the obtention of 6 is that the optimisation is carried out by considering the overall MG model. This does includes the stochastic power generation from the renewable sources.

4.3 PI controller

The design of an IMC controller entails no secrets. The first element we need in order to face the IMC design is a model of the system. As usual industrial practice and in order to show the simplicity of the approach, a first order model will be approximated on the basis of a step-response test. Assuming the production of energy and load requirements are balanced, therefore there is no disturbance in the system, a step change is applied at the control input and the generated effect in the Δf recorded. As a result, it can be seen in figure 4 that a first order plus time delay (FOPTD) model

$$P_m(s) = \frac{K_m e^{-L_m s}}{T_m s + 1} = \frac{0.496 e^{-0.1s}}{0.35s + 1} \quad (7)$$

suffices to provide a reasonable approximation of the MG dynamics. Notice that the disturbance generators (variations in the power generation and/or power load demand) are not modelled here. With this model approximation, the PI controller can be tuned by using either the IMC or the DS-d approach. The only thing that is left to choose is the λ parameter. In order to select the appropriate value for λ , a tradeoff analysis between the frequency deviation and input usage has been conducted. Input usage has been measured in terms

of the total variation (TV) of the control signal.

$$TV(u) = \sum_{k=1}^N |u(t_k) - u(t_{k-1})|$$

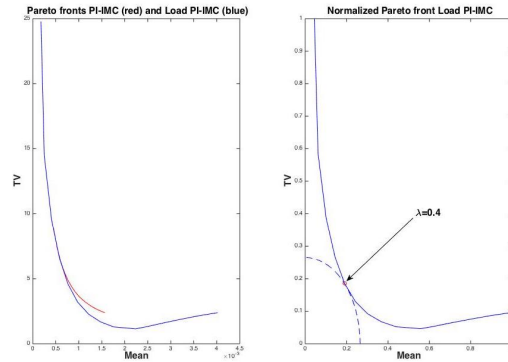
This way, in figure (5) the influence of λ on performance and control usage has been determined. For both approaches λ has been ranged between 0.1 and 1 and a sufficiently smooth approximation to the respective Pareto fronts has been determined. Due to the fact that the renewable energies are defined by stochastic processes, in order to get a well defined Pareto front, a Montecarlo experiment should be ran. In order to compare the tradeoff offered by both approaches, the objective functions have been normalised (each one of them according to its respective worst values). As it can be seen in figure (5) the solutions corresponding to the DS-d design dominates the IMC ones. It can be seen that if high accuracy (low mean) is expected, both approaches provide the same tradeoff. However, it is in the middle region and for lower levels of input usage that the load disturbance approach provides better tradeoff. In some sense this was to be expected, but the Pareto fronts confrontation provides a clear qualitative measure of the superiority of the regulatory designs. The figure also shows the points corresponding to the minimum distance to the origin. The corresponding point in the Pareto front provides the tradeoff solution that minimises (the normalised version of)

$$J = \sqrt{(\Delta_f)^2 + TV^2}$$

Whereas for the DS-d design the best tradeoff is $J = 0.26$, for the IMC PI, the best tradeoff provides $J = 0.73$. In the next section, time domain simulations of the fractional PID controller will be compared with this tradeoff DS-d solution. Note this is a slightly different version of the cost (5) where there is no need for an *a priori* selection of any weight.

5 Simulation results

This section shows time domain simulations of the MG system affected by the stochastic variations determined by the changing power generation and load demand. It is considered that the MG was operating at 1 p.u. load during $0 < t < 100$ sec and the control system performance has been evaluated then for a finite time horizon of $100 < t < 220$ sec considering changes in both the demand load and renewable generations according to Figure 3.



Figurea 5: Tradeoff analysis between the mean of the frequency deviation ($\mu(\Delta f)$) and the required input usage, $TV(u)$. Comparison of Pareto fronts for the IMC and DS-d PI

Figure 6, shows the frequency deviation from its nominal value for all the evaluation period. As it can be seen, both controllers are able to keep the frequency deviation is maintained within a ± 0.005 interval almost all the time. Even this global appreciation, the dynamics of the fractional order controlled system can be appreciated to be highly oscillating. Even during normal operation (no sudden load changes) the frequency deviation oscillation is kept within the allowed interval, the needed control signal is of considerable larger magnitude. The immediate repercussion of this manipulated variable high activity is the power demand that will be asked to the storage system, that will be continuously going up and down. This is reflected on the TV value for the Fractional PID, $TV_{FOPID} = 76.31$, whereas for the PI-IMC this value goes down to $TV_{PI-IMC} = 4.59$. In fact, the PI control signal is dramatically smoother than that of the Fractional order PID. This high control signal activity is directly translated to the system's output. Regarding the overall performance of both control systems, table (1) shows the mean and standard deviations. For both metrics, the PI controller improves performance within one order of magnitude. It should be noted that the computed standard deviation also includes the deviation generated by the large disturbances incurred because of the sudden changes in the load demand. Apart from the general, aggregated, regulation properties of the controller it is important to recover from a sudden change in the power deficit (either because of lower power generation from the renewable sources or increment of the load power demand) as fast as possible. On that respect, figure 7 shows a more detailed view of the signals corresponding to the 7sec. interval where the

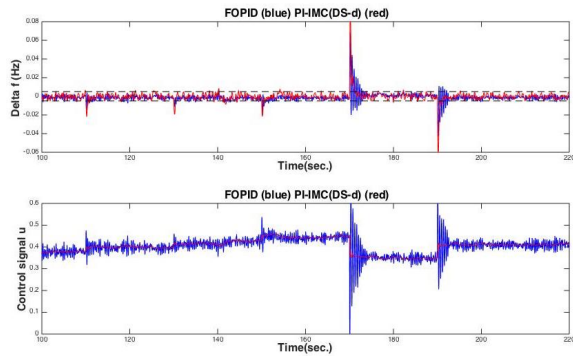


Figura 6: Regulated power system frequency deviation for the Fractional order PID and the IMC Pi designed for load disturbance

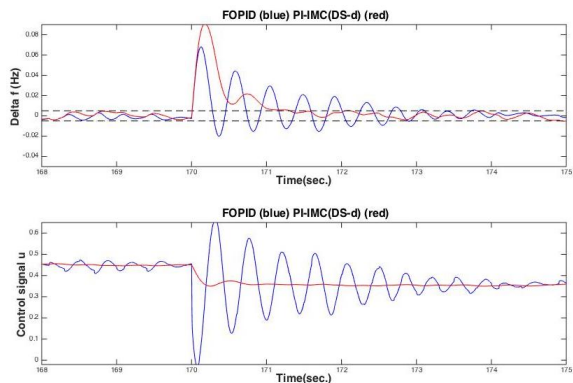


Figura 7: Comparison of recovery from a large change in the load demand

large load demand occurs. It is seen that the PI-IMC controller, recovers to the ± 0.005 band in almost 1sec, whereas the FOPID; because of the large gains incurred, takes almost 3 sec. Regarding the control signal activity, it is rather easy to take it into account because of the λ parameter in the IMC approach. This is quantitatively reflected in the tradeoff curve presented in the previous section. However it is clear the effect of increasing λ in case we need to smooth the control signal even more in order not to damage the pumps, motors, etc for the fuel supplies. As an example, if we use an IMC controller tuned with $\lambda = 0.6$, we lose some degree of performance as we move to $\mu(\Delta f) = 1.810^{-3}$ with a standard deviation of $\sigma(\Delta f) = 2.410^{-2}$. On the other hand, control signal usage has been decreased to 1.29 and the associated IAE also decreased $IAE_u^{PI-IMC} = 0.0085$.

Table 1: Performance comparison

Controller	$ \mu(\Delta f) $	$\sigma(\Delta f)$	TV(u)
Fract. PID	$2.87 \cdot 10^{-3}$	$2.84 \cdot 10^{-2}$	76.31
IMC-load (DS-d)	$0.76 \cdot 10^{-3}$	$1.75 \cdot 10^{-3}$	4.59

6 Conclusions

In this paper a Proportional-Integral controller tuning based on Internal Model Control has been proposed and applied to the frequency deviation problem in isolated microgrid systems. The considered microgrid is based on the use of renewable energy generation units such as those based on wind and solar. The major problem that these kind of systems has to encompass is the regulation compensation for sudden generated power deficits. It has been shown that the PI controller is able to command the conventional generators in a very smooth way. The major benefit of this approach is the drastic reduction in control activity and energy generated from the conventional generation units such as diesel and fuel cells.

It has to be highlighted that the tuning of the controller is very intuitive as it is based on the selection of just one parameter with a clear interpretation regarding the closed-loop control system bandwidth and, correspondingly, control signal activity.

The main proposal of the work was to keep the control algorithm complexity at a minimum. Both in its formulation and in its design. As a continuation work, other control approaches that could be recast within the IMC framework. Specially robust control approaches will be foreseen as one aspect not examined in this work is the effect of parameter variations in the system components. This robustness issue is very important as the design of the controller is based on very simple models originated from a small signal analysis.

Acknowledgements

This work was partially supported by the grant MINECO/FEDER DPI2016-77271-R. The support received from the University of Costa Rica is also greatly appreciated.

References

- [1] R. Lasseter and P. Paigi, "Microgrid: a conceptual solution," in *2004 IEEE 35th Annual Power Electronics Specialists Confer-*

- ence (*IEEE Cat. No.04CH37551*). IEEE, 2004.
- [2] C. Marnay and G. Venkataramanan, “Microgrids in the evolving electricity generation and delivery infrastructure,” in *2006 IEEE Power Engineering Society General Meeting*. IEEE, 2006.
- [3] O. Palizban, K. Kauhaniemi, and J. M. Guerrero, “Microgrids in active network management—part i: Hierarchical control, energy storage, virtual power plants, and market participation,” *Renewable and Sustainable Energy Reviews*, vol. 36, pp. 428–439, aug 2014.
- [4] B. Dong, Y. Li, and Z. Zheng, “Control strategies of DC-bus voltage in islanded operation of microgrid,” in *2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*. IEEE, jul 2011.
- [5] V. S. Sundaram and T. Jayabarathi, “Load frequency control using PID tuned ANN controller in power system,” in *2011 1st International Conference on Electrical Energy Systems*. IEEE, jan 2011.
- [6] P. K. Ray, S. R. Mohanty, and N. Kishor, “Proportional–integral controller based small-signal analysis of hybrid distributed generation systems,” *Energy Conversion and Management*, vol. 52, no. 4, pp. 1943–1954, apr 2011.
- [7] V. P. Singh, S. R. Mohanty, N. Kishor, and P. K. Ray, “Robust h-infinity load frequency control in hybrid distributed generation system,” *International Journal of Electrical Power & Energy Systems*, vol. 46, pp. 294–305, mar 2013.
- [8] Y. Han, P. M. Young, A. Jain, and D. Zimmerle, “Robust control for microgrid frequency deviation reduction with attached storage system,” *IEEE Transactions on Smart Grid*, vol. 6, no. 2, pp. 557–565, march 2015.
- [9] H. Bevrani, F. Habibi, P. Babahajyani, M. Watanabe, and Y. Mitani, “Intelligent frequency control in an ac microgrid: On-line pso-based fuzzy tuning approach,” *IEEE Transactions on Smart Grid*, vol. 3, no. 4, p. 1935–1944, dec 2012.
- [10] D. C. Das, A. Roy, and N. Sinha, “Ga based frequency controller for solar thermal-diesel-wind hybrid energy generation/energy storage system,” *Int. J. Elect. Power Energy Syst*, vol. 43, no. 1, p. 262–279, 2012.
- [11] H. Bevrani, M. Feizi, and S. Ataei, “Robust frequency control in an islanded microgrid: Hinf and mu-synthesis approaches,” *IEEE Transactions on Smart Grid*, vol. 7, no. 2, pp. 706–717, 2016.
- [12] I. Pan and S. Das, “Kriging based surrogate modeling for fractional order control of microgrids,” *IEEE Transactions on Smart Grid*, vol. 6, no. 1, jan 2015.
- [13] —, “Fractional order fuzzy control of hybrid power system with renewable generation using chaotic pso,” *ISA transactions*, vol. 62, pp. 19–29, 2016.
- [14] —, “Fractional-order load-frequency control of interconnected power systems using chaotic multi-objective optimization,” *Applied Soft Computing*, vol. 29, pp. 328–344, 2015.
- [15] D. J. Lee and L. Wang, “Small-signal stability analysis of an autonomous hybrid renewable energy power generation/energy storage system part i: Time-domain simulations,” *IEEE Transactions on Energy Conversion*, vol. 23, no. 1, pp. 311–320, 2008.
- [16] D. Rerkpreedapong, A. Hasanovic, and A. Feliachi, “Robust load frequency control using genetic algorithms and linear matrix inequalities,” *IEEE Transactions on Power Systems*, vol. 18, p. 855–861, 2003.
- [17] D. E. Rivera, M. Morari, and S. Skogestad, “Internal Model Control. 4. PID controller design,” *Ind. Eng. Chem. Des. Dev.*, vol. 25, pp. 252–265, 1986.
- [18] M. Morari and E. Zafirov, *Robust Process Control*. Englewood Cliffs, NJ, Prentice-Hall, 1989.
- [19] D. Chen and D. Seborg, “PI/PID Controller Design Based on Direct Synthesis and Disturbance Rejection,” *Ind. Eng. Chem. Res.*, vol. 41, pp. 4807–4822, 2002.
- [20] M. Shamsuzzoha and M. Lee, “Analytical design of enhanced PID filter controller for integrating and first order unstable processes with time delay,” *Chemical Engineering Science*, vol. 63, pp. 2717–2731, 2008.