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TABLE OF CONTENTS

INVESTIGATING THE COMPRESSIVE STRENGTH OF CFRP PRE-PREG SCRAP FROM AEROSPACE INDUSTRIES: COMPRESSION MOLDING	1
<i>Aya Mansour ; Haleimah Alabdouli ; Alya R. Almehairi ; Mariam Alhammadi ; Hind Alqaidy ; Waleed K. Ahmed ; Ali Hilal-Alnaqbi</i>	
POWER-DELAY-PRODUCT, AREA AND THRESHOLD-LOSS ANALYSIS OF CMOS FULL ADDER CIRCUITS	7
<i>Irfan Ahmed ; Mohammad Khalil Shahid</i>	
ASSISTIVE TECHNOLOGY FOR INTEGRATING THE VISUALLY-IMPAIRED IN MAINSTREAM EDUCATION AND SOCIETY	12
<i>Mohammed Noman ; Wessam Shehieb ; Tazeen Sharif</i>	
A GIS APPROACH OF POTENTIAL PHOTOVOLTAIC POWER SITES IN NIAMEY, NIGER	17
<i>Ibrahim Tanimoune Laouali ; Saidou Madougou ; Mounkaila Mohamed ; Yacouba Moumouni</i>	
CONTINUOUS WAVELET ANALYSIS APPLICABILITY IN AXIAL PUMPS CONDITION MONITORING (PID GAINS PERSPECTIVE)	21
<i>Molham Chikhalsouk ; Khalid Zhouri ; Yasser El Okda ; Monsif Shinneeb ; Chandra Somayaji</i>	
NEW FIBONACCI RECURRENT SYSTEMS APPLIED TO TRANSMISSION LINES INPUT IMPEDANCE AND ADMITTANCE	29
<i>Simon Hissem ; Mamadou Lamine Doumbia</i>	
INFINITE SPRING-MASS CHAIN MODEL USING FIBONACCI WAVE FUNCTIONS	37
<i>Simon Hissem ; Mamadou Lamine Doumbia</i>	
ROADCO₂: A WEB-BASED TOOL FOR ESTIMATION OF GREENHOUSE GAS EMISSIONS OF ROAD PROJECTS	45
<i>Mohammed H. Alzard ; Munjed A. Maraqa ; Rezaul Chowdhury ; Mohammad Sherif ; Timur Ibrahim Mauga ; Francisco Benicio De Albuquerque ; Khaled Nazmi Aljunadi</i>	
GENERATING POWER FROM SOLAR SPHERE DESIGN	51
<i>Hassan Abdulmouti ; Mohamed Ali Almarzooqi ; Abdelrahman Ahmed Almulla ; Mohamed Jassim Khair ; Hisham Hassan Alyasi ; Ali Ahmed Aljasmii ; Yousif Mohamed Almulla</i>	
A COMPARATIVE ANALYSIS OF VERTICAL AGRICULTURE SYSTEMS IN RESIDENTIAL APARTMENTS	55
<i>Amna Rafi Chaudhry ; Ved P Mishra</i>	
FINITE ELEMENT MODELLING OF EDGE RADIUS EFFECT IN MICRO TURNING PROCESS	60
<i>Ahmet Hascelik ; Kubilay Aslantas ; Waleed Ahmed</i>	
ANALYSIS OF DAYLIGHTING IN THE UNIVERSITY OF SHARJAH'S WALKWAYS	65
<i>Emad S. Mushataha ; Balsam Munadhil ; Amani Awni ; Farah Munadhil</i>	
PARAMAGNETIC CRYSTALLINE COBALT SELENIDE MATERIALS VIA A MOLECULAR APPROACH	71
<i>Mohammad Afzaal ; Seema Karkain</i>	
DESIGN AND IMPLEMENTATION OF THE CONTROL SYSTEM IN THE ELECTROSPINNING MACHINE OF THE NANOCOMPOSITES FOR THE MEDICAL USE	75
<i>Daniel Jancarczyk ; Mikolaj Karpinski</i>	
OPTIMISATION OF HARMONIC DROOP COEFFICIENT TO MINIMIZE POWER LOSSES IN AN ISLANDED MICROGRID	79
<i>Preetha Sreekumar ; Omar Al Trad</i>	
PI CONTROLLER BASED OPERATIONAL SCHEME TO STABILIZE VOLTAGE IN MICROGRID	83
<i>A. Elnady</i>	
SIMULATION OF ANAEROBIC CO-DIGESTION PROCESS FOR THE BIOGAS PRODUCTION USING ASPEN PLUS	89
<i>Abrar Inayat ; Mohsin Raza ; Chaouki Ghenai ; Abdallah Shanableh ; Zafar Said ; Sari Samman ; Ali Al-Mansori ; Ahmed Lazkani</i>	
DC ELECTRICAL PROPERTIES OF CHEMICALLY SYNTHESIZED POLYANILINE/PVA/MNO₂/FLY ASH COMPOSITES	94
<i>M Revanasiddappa ; D Siddalinga Swamy ; Vinay K ; Y. T. Ravikiran ; Raghavendra S C</i>	
ICAD - AN ECONOMICAL INDOOR & OUTDOOR DELIVERY VEHICLE CAPABLE OF AUTONOMOUS NAVIGATION	99
<i>A. M. Darya ; J. Rehman ; O. Aldawoud ; B. Soudan</i>	

AMIE: AN AMBIENT INTELLIGENT ENVIRONMENT FOR ASSISTED LIVING	105
<i>Marwa Kandil ; Reem Albaghdadi ; Fatemah Alattar ; Issam Damaj</i>	
A NOVEL SYNTHETIC INERTIA CONTROL FOR WIND TURBINE INTEGRATION INTO TRADITIONAL GRIDS	111
<i>Alessandro Labella</i>	
DESIGNING AN INNOVATIVE CUBESAT PAYLOAD TO INVESTIGATE MATERIAL PROPERTIES FOR UAE SPACE MISSIONS	117
<i>Kanna Abdulhadi Awad Alahbabi ; Alia Ali Obaid Alazeezi ; Waleed Khalil Ahmed</i>	
HOW TO USE KITCHEN WASTE TO PRODUCE MANURE?	122
<i>Arati Joshi ; Koustubh Yadre</i>	
TECHNIQUES OF INDOOR POSITIONING SYSTEMS (IPS): A SURVEY	126
<i>Fares Alkhawaja ; Mohammad Jaradat ; Lotfi Romdhane</i>	
SYNTHESIS OF FUNCTIONALIZED SILVER NANOPARTICLES AND ITS APPLICATION AS CHEMICAL SENSOR	134
<i>Asha Anish Madhavan ; Reem Qotainy ; Reshmi Nair</i>	
BEHAVIOR ANALYSIS TOOL FOR AUTISTIC CHILDREN USING EEG SIGNALS	138
<i>Eva Habeeb ; Noor Ghazal ; Sohaib Majzoub</i>	
QUARTER VS. HALF CAR MODEL ENERGY HARVESTING SYSTEMS	143
<i>Doaa Al-Yafeai ; Tariq Darabseh ; Abdel-Hamid I. Mourad</i>	
COMBINATION OF VIRTUAL PRIVATE NETWORK AND WIRELESS SENSOR NETWORK: PROTECTION AGAINST THE INTERFERENCE PROBLEM OF IOT	147
<i>Pramathesh Majumdar ; Ayushi Pandey ; Sunil Kumar Khatri ; Rachna Jain ; Rana Majumdar ; Ved Prakash Mishra</i>	
FOOT MODELLING FOR INVESTIGATING FOOT-DROP PROBLEM USING BIOMECHANICAL LEGS	152
<i>Omer Eldirdiry ; Riadh Zaier ; Fady Alnajjar ; Amur Al-Yahmedi ; Issam Bahadur</i>	
ON IMPLEMENTATION OF DECISION TREE INDUCTION IN CLOUD PLATFORMS	158
<i>Vasyl Martsenyuk ; Zoryana Mayhruk ; Mikolaj Karpinski ; Nazar Milian ; Igor Andrushchak ; Olga Veselskawe</i>	
CAGED QUADROTOR DRONE FOR INSPECTION OF CENTRAL HVAC DUCTS	164
<i>Ahmed Borik ; Alif Kallangodan ; Wisaaam Farhat ; Arwa Abougharib ; Mohammad A. Jaradat ; Shayok Mukhopadhyay ; Mamoun Abdel-Hafez</i>	
THE USE OF FUZZY PROMETHEE TECHNIQUE IN ANTIRETROVIRAL COMBINATION DECISION IN PEDIATRIC HIV TREATMENTS	171
<i>Berna Uzun ; Figen Sarigül Yildirim ; Murat Sayan ; Tamer Sanlidag ; Dilber Uzun Ozsahin</i>	
AN INTEGRATED ASSESSMENT OF THE HIGH-PERFORMANCE GLAZING SYSTEMS IN THE OFFICE BUILDINGS	175
<i>Youssef O. Elkhayat ; Mona G. Ibrahim ; Ahmed Abdelmonteleb M. Ali</i>	
AGILE IMPLEMENTATION-A MILESTONE FOR ACADEMICS USING SOFTWARE ENGINEERING INDUSTRY PRACTICES	181
<i>Jumana Nagaria ; Lipsa Sadath ; Suhaib Ahmed</i>	
ANALYSIS OF MUSCLE ACTIVATION PATTERNS DURING WALKING IN PATIENTS WITH FOOT DROP: INSIGHTS FOR THE DESIGN OF AN ADVANCED FES CONTROLLER	187
<i>Aikaterini D. Koutsou ; Fady Alnajjar ; Sergio Lerma Lara ; Beatriz Moral ; Riadh Zaier ; Juan C. Moreno</i>	
MOBILE CLASSROOM-BLENDED LEARNING THROUGH USE OF TECHNOLOGY	193
<i>Gomathy Krishnan ; Wahida Dastakeer</i>	
SIZING OF A CAR PARKING PHOTOVOLTAIC SYSTEM: AN ECONOMIC ANALYSIS	199
<i>Nawal Nader Al Awadhi ; Yacouba Moumouni ; Ahmed Khodary</i>	
EFFECT OF VIBRATION AND CHEMICAL SOLUTION ON MECHANICAL PROPERTIES OF FIBERGLASS REINFORCED COMPOSITES	203
<i>Mohammad Mahmoud Al Wedian ; Sabin Kumar Mishra</i>	
EFFECTS OF CYLINDER SHAPE ON THE PERFORMANCE OF VORTEX INDUCED VIBRATION FOR AQUATIC RENEWABLE ENERGY	206
<i>Abid Abdul Azeez ; Sharul Sham Dol ; Mohammad S. Khan</i>	
FLEXURAL RESPONSE OF RC BEAMS REINFORCED WITH HSS BARS USING FEA	210
<i>Saif Aldabagh ; Farid Abed ; Sherif Yehia</i>	
IOT-BASED INTELLIGENT WASTE BIN	215
<i>Moath Awawdeh ; Anees Bashir ; Tarig Faisal ; Irfan Ahmad ; Mohammad Khalil Shahid</i>	
ISOTHERMAL COMPRESSED AIR SYSTEM FOR INTERNAL CHANNEL COOLING	221
<i>Amin Safi ; Emad Elnajjar ; Mohammad Hamdan</i>	

IMPROVING THE FUNCTIONAL PERFORMANCE OF OUTDOOR SPACES IN HOT ARID REGION USING PHOTOVOLTAICS SYSTEMS	225
<i>Lucienne G. Basaly ; Mona G. Ibrahim ; Nancy Mahmoud Badawy ; Mohammad Refaat M. Abdelaal ; Ahmed Abdelmonteleb M. Ali</i>	
AN ANALYSIS TOOL FOR THE DETECTION OF METHANE IN THE MARTIAN ATMOSPHERE	230
<i>K C Utsav ; Mohamad Muflehi</i>	
NUMERICAL MODELLING OF BIOMASS COMBUSTION ON MOVING GRATES	236
<i>K.U.C. Perera ; M. Narayana ; Sanjeeva Witharana</i>	
A PILOT STUDY ON ABLUTION SPACE SAFETY IN MOSQUES : SLIP-RESISTANCE ASSESSMENTS OF ABLUTION FLOORINGS FROM A VIEWPOINT OF FALL INCIDENTS	242
<i>In-Ju Kim ; Omar Hassan Omar</i>	
SAFETY ASSESSMENTS OF ABLUTION FLOORS IN MOSQUES: : MEASUREMENTS OF SLIP RESISTANCE PERFORMANCE AND SURFACE FEATURES	247
<i>In-Ju Kim ; Omar Hassan Omar</i>	
CFD INVESTIGATION OF THE EFFECT OF CEREBRAL ANEURYSMS SIZE ON WALL STRESSES AND STRAIN	253
<i>Mohammad O. Hamdan ; Hashem M. Alargha ; Saud Khashan ; Waseem H. Aziz</i>	
ADAPTING THE MACHINE LEARNING GRID PREDICTION MODELS FOR FORECASTING OF RESOURCES ON THE CLOUDS	260
<i>Sena Seneviratne ; Sanjeeva Witharana ; Adel N Toosi</i>	
CREATING A COURSE TEACHING MAP FOR STEM COURSES	266
<i>Elsheikh Mohamed Ahmed Elsheikh</i>	
THERMAL DESIGN OF A PORTABLE PCM COOLER FOR AN INSULATED ROOM	271
<i>P. Venkata Reddy ; Vishal Naranje</i>	
IS LIFELONG LEARNING SKILL THE ONLY LIFE-LASTING SKILL ENGINEERING GRADUATES EVER NEED? : TEACHING LIFELONG LEARNING SKILL IN THE CLASSROOM	278
<i>Sadegh Babaii Kochekserei</i>	
NANO-ENHANCED PCM FOR ENERGY STORAGE	284
<i>Zafar Said ; Hanin Zeyad ; Tasnim I. Eisa ; Mamdouh El Haj Assad</i>	
WHITE BLOOD CELL DETECTION AND COUNTING BASED ON GENETIC ALGORITHM	290
<i>M. Khodashenas ; H. Ebrahimpour-Komleh ; A. M. Nickfarjam</i>	
A SYNTHESIS OF VITREOUS CARBON FROM BROMINE FLAME RETARDED HIGH IMPACT POLYSTYRENE	294
<i>Sylvia Oleszek ; Mariusz Grabda ; Adline Nwodo ; Takashi Nakamura ; Alfons Buekens</i>	
COMPARISON OF HALF CUT SOLAR CELLS WITH STANDARD SOLAR CELLS	298
<i>Arati Joshi ; Afrah Khan ; Afra Sp</i>	
ENHANCING USER NAVIGATION EXPERIENCE, OBJECT IDENTIFICATION AND SURFACE DEPTH DETECTION FOR "LOW VISION" WITH PROPOSED ELECTRONIC CANE	301
<i>Vinod Kumar Shukla ; Amit Verma</i>	
MULTI-CLASS SURVEILLANCE FOR ACUTE RESPIRATORY DISTRESS SYNDROME USING BELIEF FUNCTIONS	306
<i>Aline Taoum ; Hassan Amoud ; Farah Mourad-Chehade</i>	
INVESTIGATING ON MOBILE USAGE PATTERNS AND REASONS BY UNIVERSITY STUDENTS IN THE UAE INSIDE CLASSROOMS	312
<i>Farah A. Genena ; Asel A. Mwafy ; Mouza S. Al Mansoori ; Abdel-Hamid I. Mourad</i>	
OPTIMIZATION OF PROCESS PARAMETERS FOR ORGANIC MUNICIPAL SOLID WASTE TORREFACTION	317
<i>D. G. C. Wickramasinghe ; M. Narayana ; Sanjeeva Witharana</i>	
REDEFINING BANKING AND FINANCIAL INDUSTRY THROUGH THE APPLICATION OF COMPUTATIONAL INTELLIGENCE	322
<i>Princy Agarwal</i>	
A COMPARATIVE ANALYSIS OF RETROFIT VERSUS NEW CONSTRUCTION : THE CASE STUDY OF MOHAMMED BIN RASHID HOUSING ESTABLISHMENT HEADQUARTER (MBRHE)	327
<i>Vittorino Belpoliti ; Raghad A. Ghazal ; Nesrine O. Ousadou ; Dana G. Obaid</i>	
ESTIMATION OF VOLTAGE SYMMETRICAL COMPONENTS AND CURRENT HARMONICS USING MULTI-OUTPUT KALMAN FILTER	333
<i>N. Alawadhi ; A. Elnady ; S. Sinan</i>	
DESIGN OF A COST-EFFICIENT TERAHERTZ SYSTEM FOR BIOMEDICAL APPLICATIONS	338
<i>Sara Boumali ; Bouhdid Imane ; Rezgoune Baha Eddine ; Mohamed Taoufik Benhabiles ; Fouad Kerrou</i>	

AUTONOMOUS MOTION TRACKING FOR DYNAMIC OBJECTS USING A TEMPORAL QUAD-TREE ALGORITHM.....	343
<i>Baraa Al Jilani ; Tamer Rabie ; Mohammed Baziyad</i>	
NEURAL NETWORK PATH FOLLOWING FOR DIFFERENTIAL DRIVE VEHICLE.....	348
<i>Madoka Asai ; Gan Chen ; Isao Takami</i>	
PARAMETRIC STUDY OF GEOTHERMAL PARALLEL FLOW DOUBLE-EFFECT WATER-LIBR ABSORPTION CHILLER.....	354
<i>Mamdouh El Haj Assad ; Zafar Said ; Ali Khosravi ; Tareq Salameh ; Mona Albawab</i>	
SELECTION OF THE MOST APPROPRIATE ANTIRETROVIRAL MEDICATION IN DETERMINED AGED GROUPS (=3 YEARS) OF HIV-1 INFECTED CHILDREN.....	360
<i>Nazife Sultanoglu ; Berna Uzun ; Figen Sarigul Yildirim ; Murat Sayan ; Tamer Sanlidag ; Dilber Uzun Ozsahin</i>	
USAGE OF HOUGH TRANSFORM FOR EXPIRY DATE EXTRACTION VIA OPTICAL CHARACTER RECOGNITION.....	366
<i>Davide Scazzoli ; Giulia Bartezzaghi ; Deniz Uysal ; Maurizio Magarini ; Marco Melacini ; Marco Marcon</i>	
COMPREHENSIVE SURVEY OF MASSIVE MIMO FOR 5G COMMUNICATIONS.....	372
<i>Aliya Shaikh ; Maninder Jeet Kaur</i>	
USERS PERCEPTIONS AND EXPERIENCE ON BLACKBOARD LEARN FUNCTIONALITIES.....	377
<i>Panthayil. K. Baburajan ; Silishi Noushad ; Amjad. A. Shaikh</i>	
REVIEW ON SYSTEM IDENTIFICATION FOR QUADROTOR UNMANNED AERIAL VEHICLE (UAV).....	383
<i>Ari Legowo ; Erwin Sulaeman ; Danial Rosli</i>	
EFFECT OF HARSH ENVIRONMENTAL CONDITIONS ON THE BOND-DEPENDENT COEFFICIENT OF GFRP BARS IN CONCRETE BEAMS.....	391
<i>Farid Abed ; Nouran Elmesalami</i>	
CONSTRUCTION OF URDF MODEL BASED ON OPEN SOURCE ROBOT DOG USING GAZEBO AND ROS.....	396
<i>Pratik Vyavahare ; Sivaranjani Jayaprakash ; Krishna Bharatia</i>	
A COMPARISON FOR LIVER CANCER TREATMENT ALTERNATIVES.....	401
<i>Musa Sani Musa ; Dilber Uzun Ozsahin ; Ilker Ozsahin</i>	
EVALUATION AND SIMULATION OF COLON CANCER TREATMENT TECHNIQUES WITH FUZZY PROMETHEE.....	405
<i>Dilber Uzun Ozsahin ; Kudakwashe Nyakuwanikwa ; Tapiwa Wallace ; Ilker Ozsahin</i>	
EVALUATION OF STERILIZATION METHODS FOR MEDICAL DEVICES.....	411
<i>Mubarak Taiwo Mubarak ; Ilker Ozsahin ; Dilber Uzun Ozsahin</i>	
ENHANCED MECHANICAL PROPERTIES OF GLASS FIBER/EPOXY COMPOSITES USING NANOCCLAY.....	415
<i>M. S. Senthil Kumar ; Chithirai Pon Selvan ; P. S. Sampath ; K. Raja ; Reshmi Nair</i>	
FUZZY PROMETHEE FOR RANKING PANCREATIC CANCER TREATMENT TECHNIQUES.....	424
<i>Ilker Ozsahin ; Dilber Uzun Ozsahin ; Kudakwashe Nyakuwanikwa ; Tapiwa Wallace Simbanegavi</i>	
MULTI-OBJECTIVE OPTIMIZATION OF AIR CONDITIONING SYSTEM WITH THE LOW GWP REFRIGERANT R1234YF USING GENETIC ALGORITHM.....	429
<i>Juan Garcia ; Ali Khosravi ; Ricardo Poley ; Mamdouh Assad ; Luiz Machado</i>	
MULTI DOF SYSTEM MODELLING-TRANSFER FUNCTION AND STATE VARIABLE APPROACHES.....	436
<i>Fesmi Abdul Majeed ; Mazin Abuharaz</i>	
TOXICITY ASSESSMENT OF DATE PIT ACTIVATED CARBON NANOMATERIALS IN HEPATOCYTES.....	442
<i>Betty Titus Mathew ; Shaima Raji ; A-H. I. Mourad ; Ali Hilal-Alnaqbi ; Khaled A. El-Tarabily ; Amr Amin ; Fadi Alnaimat ; Bobby Mathew</i>	
REMOVAL OF PFASS FROM WATER WITH IONIC LIQUIDS: QUANTUM-MECHANICAL AND EXPERIMENTAL STUDIES.....	448
<i>Mariusz Grabda ; Sylwia Oleszek</i>	
INTELLECTUAL HUMAN-OBJECT CLASSIFICATION USING GENETIC ALGORITHM.....	452
<i>N. Kavitha ; K. Ruba Soundar ; V. Balasubramaniam</i>	
ISOTHERMAL MELT CRYSTALLIZATION OF POLYETHYLENE NANOCOMPOSITES WITH THERMALLY REDUCED GRAPHENE AND CARBON BLACK.....	457
<i>Ahmed Z. A. Abuibaid ; Muhammad Z. Iqbal</i>	
EMPLOYABILITY AND HIRING TRENDS OF ENGINEERING JOB ASPIRANTS IN UAE.....	462
<i>Shanthi Rajan ; Archana Pandita</i>	
ADVANCING KNOWLEDGE IN TECHNOLOGICAL INNOVATION : INNOVATION MAPPING MODEL.....	468
<i>Alaa M. Ubaid ; Mustafa Sahban ; Oussama Hammad ; Ayman Ramadan ; Refaat Abdel-Razek</i>	

MULTI-FUNCTIONAL SAFETY JACKET FOR FIREFIGHTERS	475
<i>Amal Al Hamadi ; Mariam Al Hamadi ; Nawal Al Awadi ; Yacouba Mounouni</i>	
A PILOT STUDY ON CIVIL ENGINEERING STUDENTS ACCEPTANCE TO A FLIPPED CLASSROOMS PEDAGOGY	480
<i>Hamad Al Jassmi ; Salini Ramesh ; Tamer El-Maaddawy ; Omniah Alqahtani ; Waleed Khalil Ahmed</i>	
SOPHOMORE DESIGN PROJECT OF A VALUE DRIVEN UNMANNED AIR VEHICLE DESIGN	484
<i>Evangelos Papageorgiou ; Serdar Dalkilic ; Eleni-Eleftheria Kamperi</i>	
COMPETITIVE ADSORPTION ON DIATOMACEOUS EARTH PARTICLES	490
<i>Helanka J. Perera ; Frank D. Blum</i>	
SMART TRAFFIC MANAGEMENT SYSTEM FOR FOGGY WEATHER CONDITIONS	494
<i>Fesmi Abdul Majeed ; Basma Murad ; Khawla Khalil ; Asma Mohamed ; Fatima Ali ; Sendeyah Obaid ; Sara Ahmed</i>	
INTELLIGENT TUTORING FOR INFORMED FEEDBACK IN INTERACTIVE LEARNING ENVIRONMENTS	497
<i>Sadia Riaz ; Arif Mushtaq ; Maninder Jeet Kaur</i>	
BOOSTING TEACHING EXPERIENCE IN MECHANICAL ENGINEERING COURSES USING ADDITIVE MANUFACTURING TECHNOLOGIES	503
<i>Issah M. Alhamad ; Waleed K. Ahmed ; Hayder Z. Ali</i>	
SMART GRID INTELLIGENT ENERGY MANAGEMENT SYSTEM WITH COST OPTIMIZATION IN POWER SYSTEM	509
<i>Hafiz Fuad Usman ; Shahzaib Hamid ; Waheed Aftab Khan ; Majid Ali ; Saif Ur Rehman</i>	
DETERMINATION OF POST-EXPOSURE PROPHYLAXIS REGIMEN IN THE PREVENTION OF POTENTIAL PEDIATRIC HIV-1 INFECTION BY THE MULTI-CRITERIA DECISION MAKING THEORY	515
<i>Murat Sayan ; Nazife Sultanoglu ; Berna Uzun ; Figen Sarigul Yildirim ; Tamer Sanlidag ; Dilber Uzun Ozsahin</i>	
FINANCING THE CLIMATE CHANGE THROUGH GREEN (CLIMATE SUSTAINABLE) BONDS	520
<i>Arindam Banerjee</i>	
EFFECT OF SHALLOUNESS ON THE FLOW FIELD OF A HORIZONTAL TURBULENT WATER JET	524
<i>Monsif Shinneeb ; Khalid Zouhri ; Molham Chikhalsouk</i>	
REDUCED COMPLEXITY TRAINING SYMBOL FOR FAST SYNCHRONIZATION OF OFDM-BASED NETWORKS	530
<i>Zaid S. Al-Aubaidy ; Munther Gdeisat ; Saloa M. Ali</i>	
EMBEDDED VENTILATION AIR CONDITIONING SYSTEM FOR PROTECTION PURPOSES WITH IOT CONTROL	536
<i>Moath Awawdeh ; Anees Bashir ; Tarig Faisal ; Khawla Alhammadi ; Mouza Almansori ; Sara Almazrouei</i>	
THERMODYNAMIC ANALYSIS OF GEOTHERMAL SERIES FLOW DOUBLE-EFFECT WATER/LIBR ABSORPTION CHILLER	542
<i>Mamdouh El Haj Assad ; Ali Khosravi ; Zafar Said ; Mona Albawab ; Tareq Salameh</i>	
CAMEL MONITORING AND TRACKING SYSTEM ACROSS FENCED HIGHWAYS	548
<i>Abdel Ilah N. Alshbatat ; Fawaz Hrahsheh ; Tarig Faisal</i>	
DESIGN OF A SMALL HORIZONTAL AXIS WIND TURBINE	553
<i>Yasser El-Okda ; Kamel Adref ; Molham Chikhalsouk ; Hussni Al Hajjar</i>	
ACCUMULATION OF HEAVY METALS ON SOIL IRRIGATED WITH TREATED WASTEWATER AT AL AL-BAYT UNIVERSITY-JORDAN	560
<i>Anf Hanna Ziadat ; Anwar Jiries ; Ibrahim Alojail</i>	
RESIDENTIAL PEAK COOLING LOAD AND PEAK SOLAR TIME FOR TYPICAL UAE CONDITIONS	566
<i>Kamel Adref ; Yasser Elokda ; Molham Chikhalsouk ; Asma Alebri ; Hamda Alhosani</i>	
IMPACT OF TIME OF USE TARIFF AND DEMAND PROFILES ON PROSUMERS IN PEER-TO-PEER ENERGY SHARING SCHEME	571
<i>K. Kusakana</i>	
AUTOMATED DESIGN PLATFORM FOR EDUCATIONAL ROBOTS	578
<i>Tiago Caldeira ; Jorge I. Montalvo Navarrete</i>	
SMART MANUFACTURING OF 3D PRINTED ROBOTS	583
<i>Jorge I. Montalvo Navarrete ; Tiago Caldeira</i>	
LATENT FINGERPRINT DEVELOPMENT WITH BIOSYNTHESIZED NANO RUST	588
<i>Asha Anish Madhavan ; Bhoopesh Kumar Sharma</i>	
BEHAVIOR OF RC BEAMS EXTERNALLY STRENGTHENED WITH MORTAR BONDED STEEL MESH	592
<i>Kais A. Douier ; Rami Hawileh ; Jamal A. Abdalla</i>	

REVIEW OF SECURITY IN MOBILE EDGE COMPUTING WITH DEEP LEARNING	595
<i>Prashanth Subramaniam ; Maninder Jeet Kaur</i>	
EVALUATION OF BFRP RC BEAMS UNDER FLEXURE	600
<i>Farid Abed ; Mustafa Al-Mimar ; Noor Tello</i>	
RENEWABLE AND ANONYMOUS BIOMETRICS-BASED REMOTE USER AUTHENTICATION SCHEME USING SMART CARDS FOR TELECARE MEDICINE INFORMATION SYSTEM	604
<i>Alawi A. Al-Saggaf ; Tarek R Sheltami</i>	
THE APPLICATION OF DEEP LEARNING TO QUANTIFY SAT/VAT IN HUMAN ABDOMINAL AREA	610
<i>Walid Zgallai ; Teye Brown ; Asma Murtada ; Sara Ali ; Amina Haji ; Khawla Khalil ; Maryam Omran ; Entesar Z. Dalah ; Moez Al-Islam E. Faris ; Abdulmunhem K. Obaideen</i>	
INVESTIGATION OF BIOSENSING BIAS WITH SINGLE CELLS LOCATED IN RECTANGULAR MICROWELLS	615
<i>Ayoola T. Brimmo ; Pavithra Sukumar ; Mohammad A. Qasaimeh</i>	
SIMPLIFIED MATHEMATICAL MODELLING OF WING TIP VORTICES	620
<i>Aziz Al-Mahadin ; Mohammad Almajali</i>	
DEEP LEARNING AI APPLICATION TO AN EEG DRIVEN BCI SMART WHEELCHAIR	626
<i>Walid Zgallai ; John Teye Brown ; Afnan Ibrahim ; Fatma Mahmood ; Khulood Mohammad ; Maitha Khalfan ; Maryam Mohammed ; Maryam Salem ; Noof Hamood</i>	
AUTOMATIC SPEECH RECOGNITION AND ITS VISUAL PERCEPTION VIA A CYMATICS BASED DISPLAY	631
<i>Saeed Mian Qaisar ; Hannan Alsharif ; M. Akbar ; A. Abdullah</i>	
SHEAR BEHAVIOR OF RC BEAMS CAST WITH LAVA LIGHTWEIGHT AGGREGATES	635
<i>Waleed Nawaz ; Rami Hawileh ; Jamal A Abdalla ; H Ataya ; H.S Alajmani ; I.H Abuzayed ; H.A Mohamed</i>	
EQUIVALENT PERMEABILITY OF ADJACENT POROUS REGIONS	639
<i>Muhammad Ali A. ; Rehan Umer ; Kamran A. Khan</i>	
INTERPRETING TRASMITARRAYS FAR-FIELD PERFORMANCE USING ITS NEAR FOCAL REGION FIELDS	643
<i>E'qab R. Almajali ; Abdulkader Hamid ; Saqer S. Alja'afreh ; Ashraf Tahat</i>	
A SPEECH TO MACHINE INTERFACE BASED ON PERCEPTUAL LINEAR PREDICTION AND CLASSIFICATION	647
<i>Saeed Mian Qaisar ; Noofa Hainmad ; Raviha Khan ; Rawan Asfour</i>	
FEASIBILITY STUDY OF USING PHOTOVOLTAIC (PV), WIND AND BIOGAS RENEWABLE ENERGY SYSTEM IN SOUTH AUSTRALIA HOUSEHOLD TO MAXIMIZE THE ENERGY PRODUCTION FROM RENEWABLE SOURCES	651
<i>Chi Sing Kwok ; Sathyan Krishnan ; Birhane Haile Tesfagergis ; Hung Yao Hsu</i>	
BRAIN TUMOR CLASSIFICATION AND SEGMENTATION USING FASTER R-CNN	656
<i>H. N. T. K. Kaldera ; Shanaka Ramesh Gunasekara ; Maheshi B. Dissanayake</i>	
BUSINESS CONTINUITY MANAGEMENT FRAMEWORK OF INTERNET OF THINGS (IOT)	662
<i>Jasim Al Ali ; Qassim Nasir ; Fikri T. Dweiri</i>	
ANALYSIS OF ACOUSTIC TESTING ON STATIC CHEVRONS NOZZLES	669
<i>Jerrin Thadathil Varghese ; Sarath Raj N.S ; Mohamed Sufyan Shafti</i>	
IN-DEPTH EVALUATION OF PROCESS VARIABLES IN ABRASIVE WATERJET CUTTING OF ALUMINA CERAMICS	675
<i>Chithirai Pon Selvan ; Sahith Reddy Madara ; Swaroop Ramaswamy Pillai ; Ramesh Vandanapu</i>	
DESIGNING AND DEVELOPING INNOVATIVE STRUCTURAL ENGINEERING FAILURE EXPERIMENT USING ADDITIVE MANUFACTURING TECHNOLOGY	679
<i>Asma Aldarmaki ; Alyazia Alshamsi ; Waleed K Ahmed ; Hamad Al Jassmi</i>	
ASSESSING COMMERCIAL 3D SCANNERS TO REPRODUCE STRUCTURAL ELEMENTS	685
<i>Alyazia Hamad Al-Shamsi ; Asma Rashed Al-Darmaki ; Waleed K Ahmed ; Hamad Al-Jassmi</i>	
THERMAL CONDUCTIVITY OF CARBON FOAM ASSUMING SPHERICAL UNIT CELL	693
<i>Mohammad Almajali ; Aziz Al-Mahadin</i>	
DEVELOPMENT OF A KNOWLEDGE BASED DESIGN ASSISTING SYSTEM FOR COMPLIANT MACHINE PARTS	697
<i>Laith Abdullah Al-Juboori</i>	
EFFECT OF LEARNING FOREIGN LANGUAGES ON STEM EDUCATION	702
<i>Ishan Maheshwari ; Piyush Maheshwari</i>	
OPTIMIZATION OF CONTROL VARIABLES IN LASER WELDING OF DISSIMILAR MATERIALS USING GA APPROACH	706
<i>Renangi Sandeep ; M. Chithirai Pon Selvan ; D. Sudhakara ; M. S. Senthil Kumar</i>	

PERFORMANCE ANALYSIS OF NANO-CRYSTALLINE DIAMOND (NCD) COATING IN MICRO-MILLING OF ALUMINUM ALLOY	710
<i>Kubilay Aslantas ; Waleed Ahmed</i>	
TWO PHOTON DOSE ENGINES FOR ACCURATE AND FAST VOLUMETRIC MODULATED ARC THERAPY	716
<i>Abdulla Ali Desmal ; Yang Sheng ; Hunter Stephens ; Yaorong Ge ; Qiuwen Wu ; Jackie Wu</i>	
SOLAR AND WIND POWER IN ENHANCING UNCONVENTIONAL OIL RECOVERY BY UNDERGROUND HEAT INDUCTION	720
<i>Ahmad E'mar ; Yahia Alraie ; Fahad Ismail ; Saad Al-Afnan</i>	
DESIGN AND DEVELOPMENT OF LIGHTWEIGHT-HIGH ENDURANCE UNMANNED AERIAL VEHICLE FOR OFFSHORE SEARCH AND RESCUE OPERATION	725
<i>Saif Eldin Eid ; Sharul Sham Dol</i>	
SPINAL FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI) ON HUMAN STUDIES: A LITERATURE REVIEW	730
<i>Sajedah Al-Momani ; Salam Dhou</i>	
ESTIMATING TI-6AL-4V COATING THICKNESS OVER SS304 SUBSTRATE USING SIMULATED SINGLE-FREQUENCY APPARENT EDDY CURRENT CONDUCTIVITY	735
<i>Zain A. Ansari ; Bassam A. Abu-Nabah ; Maen Alkhader</i>	
LARGE-SCALE EMPIRICAL MODEL FOR A 2.4 GHZ WIRELESS NETWORK IN AN OUTDOOR ENVIRONMENT	740
<i>Mariam Alhammadi ; Mouza Almansoori ; Isaias Tesfu ; Daniel Habte ; Irfan Ahmed</i>	
IMPROVING STUDENTS CONCEPTUAL UNDERSTANDING OF CALCULUS BASED PHYSICS USING PROBLEM BASED LEARNING APPROACH ON AN E-LEARNING PLATFORM APPLIED TO ENGINEERING EDUCATION	744
<i>Sandhya Kattayat ; Smitha Josey</i>	
INFLUENCE OF RADIATION AT DIFFERENT RF FREQUENCIES ON BOVINE SERUM ALBUMIN STABILITY IN THE ASPECT OF BIOSENSOR.....	750
<i>Aleksandra Klos-Witkowska ; Vasyl Martsenyuk ; Mikolaj Karpinski ; Ibrahim Obeidat</i>	
A REVIEW ON THE STRUCTURE, PROPERTIES AND CHARACTERIZATION OF 2D MOLYBDENUM DISULFIDE.....	755
<i>Sharon Santhosh ; Asha Anish Madhavan</i>	
ANALYSIS OF COOLING PROCESS OF SINGLE POINT CUTTING TOOL BY SURFACE DROPLET IMPINGEMENT AND INTERNAL TRANSPIRATION METHODS	760
<i>P. Venkata Reddy ; Vishal Naranje</i>	
ROBUST REAL-TIME EMBEDDED FACE DETECTION USING FIELD PROGRAMMABLE GATE ARRAYS (FPGA).....	765
<i>Afnan Alahmadi ; Saeed Mian Qaisar</i>	
SCENE TO TEXT CONVERSION AND PRONUNCIATION FOR VISUALLY IMPAIRED PEOPLE	770
<i>Saeed Mian Qaisar ; Raviha Khan ; Noofa Hammad</i>	
UNDERSTANDING THE INFLUENCE OF REPLACING CEMENT WITH GGBS ON COMPRESSIVE AND FLEXURAL STRENGTHS OF CONCRETE AT MEDIUM WORKABILITY CONDITIONS	774
<i>Ramesh Vandhanapu ; Vidya Mohanan ; Chithirai Pon Selvan</i>	
STUDY ON THE EFFECT OF MG DOPANT ON THE PROPERTIES OF ZNO THIN FILM PREPARED BY SOL GEL.....	778
<i>Tang Xiao Fen ; Ari Legowo ; Ali Shaitir ; Agus Geter Edy Sutjipto</i>	
COMPUTATIONAL STUDY OF HEAT TRANSFER AUGMENTATION IN RECTANGULAR CHANNEL WITH UPPER WALL EXPOSED TO CONSTANT HEAT FLUX.....	786
<i>Abed Mennad ; Najeed U. Khan ; Muhammad M. Janjua ; Altaf H. Khan</i>	
UNIVERSITY HOSPITAL IN SHARJAH DIAGNOSTIC REFERENCE LEVELS FOR MULTI-DETECTOR CT EXAMINATIONS.....	795
<i>Entesar Zawam Dalah ; Hiba Waleed Al-Dhubhani ; Hussein M Elmehdi ; Abdulmunhem Obaideen ; Mohammed Sammy Weis ; Omar Adas</i>	
SYSTEMIC VIEW TO NURTURE PROFESSIONAL ENGINEERS - A ROADMAP	800
<i>Umesh Bhushi ; Omar Altrad ; Manjunath Bhandary</i>	
INVESTIGATING PHOTOCATALYTIC FUNCTIONAL PROPERTY OF TIO2 THIN FILM DEVELOPED BY NOVEL DEPOSITION METHOD	805
<i>Amjad. A. Shaikh</i>	
CASCADING FAILURE ANALYSIS BASED EARLY DESIGN FOR A COMPLEX ENGINEERING SYSTEM.....	809
<i>Khulood Ismaeel Alhosani ; Ameena Al-Sumaiti ; Khalid Al-Ali</i>	

THE EFFECT OF CURVATURE AND LAYUP OF AIRCRAFT TYPE CFRP LAMINATE ON THE SPRINGBACK AFTER CURING PROCESS.....	814
<i>Yulfian Aminanda ; Ari Legowo ; Mohd Nazreen Bin Mohd Nasir</i>	
PHYSICALLY UNCLONABLE FUNCTIONS (PUFS): A SYSTEMATIC LITERATURE REVIEW.....	819
<i>Mohammed Al-Haidary ; Qassim Nasir</i>	
IOT DEVICES SECURITY USING RF FINGERPRINTING.....	825
<i>Douae Nouichi ; Mohamed Abdelsalam ; Qassim Nasir ; Sohail Abbas</i>	
WEAR PERFORMANCE ANALYSIS OF ALUMINUM MATRIX COMPOSITES USING ARTIFICIAL NEURAL NETWORK.....	832
<i>Amir Hussain Idrisi ; Abdel Hamid Ismail Mourad</i>	
TRACKING CONTROL OF SERIAL ROBOT MANIPULATOR USING ACTIVE DISTURBANCE REJECTION CONTROL.....	837
<i>Mahmoud A. Y. Abdallah ; Rouf Fareh</i>	
EFFECTS OF CLIMATE CHANGE ON RIVER FLOW STOCHASTIC APPROACH.....	842
<i>Elgaali Elgaali ; Zeyad Tarawneh</i>	
RECYCLING OF WASTEWATER FROM CAR-WASHING FACILITIES FOR LANDSCAPING APPLICATIONS.....	847
<i>Majid Akram ; Elgaali Elgaali</i>	
USE OF RECYCLED CONSTRUCTION WASTE MATERIALS FOR PIPELINE BEDDING APPLICATION.....	851
<i>Majid Akram ; Elgaali Elgaali ; Samir Janho</i>	
A NOVEL FLARE MANEUVER GUIDANCE FOR APPROACH AND LANDING PHASE OF A REUSABLE LAUNCH VEHICLE.....	855
<i>Aysha S. Hameed ; G. R. Bindu</i>	
EFFECT OF ANNEALING TEMPERATURE ON THE ANALYSIS AND CHARACTERIZATION OF CU₂ZN_{0.6}CD_{0.4}SNS₄ QUINTEARNARY ALLOY NANOSTRUCTURES DEPOSITED ON SILICON SUBSTRATE.....	861
<i>A. S. Ibraheam ; Ali Abu Odeh ; Yarub Al-Douri</i>	
ASSESSMENT OF PUBLIC-PRIVATE PARTNERSHIP MODELS FOR HOUSING DELIVERY IN THE UAE.....	865
<i>Khalifa Alteneiji ; Sabah Alkass ; Saleh Abu Dabous</i>	
PROCESS PARAMETERS OPTIMIZATION OF TUNGSTEN INERT GAS WELDING BY TAGUCHI METHOD.....	869
<i>Mohammad Khalid</i>	
DEVELOPMENT OF INERT CERAMIC FOR INDUSTRIAL APPLICATION BASED ON TERNARY PHASE DIAGRAM OF POTASSIUM OXIDE-ALUMINUM OXIDE-SILICON DIOXIDE.....	874
<i>Agus Geter Edy Sutjipto ; Anwaruddin Hisyam ; Nurjannah Salim ; Mohd Hasbi Ab Rahim ; Ari Legowo ; Moh Hanafi Ani</i>	
A NEW DUAL-ELEMENT MULTIMODE MIMO ANTENNA FOR METAL-RIMMED SMARTPHONE.....	878
<i>Saqer Aljaafreh ; Mallak H. Alshamaileh ; Eqab Almajali</i>	
A MICROFLUIDIC DEVICE WITH PENETRATING MICROELECTRODE ARRAY FOR FOCUSING OF CELLS USING DIELECTROPHORESIS.....	881
<i>Nosayba Al-Azzam ; Bobby Mathew ; Waqas Waheed</i>	
BUILDING ENERGY MANAGEMENT SYSTEM: AN OVERVIEW OF RECENT LITERATURE RESEARCH.....	885
<i>Safa Alattas Alhashmi ; Ameena Saad Al-Sumaiti ; Muhammad Wajahat Hassan ; Muhammad Babar Rasheed ; Sergio Raul Rivera Rodriguez ; Rajesh Kumar ; Ehsan Heydarian-Forushani</i>	
A MATHEMATICAL MODEL OF ARTERIOSCLEROSIS ONSET.....	890
<i>Hiroyuki Kagami</i>	
PROJECT BASED LEARNING (PBL) APPROACH FOR IMPROVING THE STUDENT ENGAGEMENT IN VOCATIONAL EDUCATION : AN INVESTIGATION ON STUDENTS' LEARNING EXPERIENCES & ACHIEVEMENTS.....	893
<i>Vidhya K Viswambaran ; Shimna Shafeek</i>	
FLUID STRUCTURE INTERACTION SIMULATION STUDY OF TRAVELLING WAVE VALVE-LESS MICRO PUMP IN FLUID DELIVERY.....	899
<i>Kalimuthu Govindarajua ; Pradeep Hegdea ; Irfan Anjum Badruddinb ; Ibrahim Obaid Ahmad Mohammad Alsharifa</i>	
A COMPARATIVE STUDY OF STEEL AND COMPOSITE HELICAL SPRINGS USING FINITE ELEMENT ANALYSIS.....	904
<i>Clifton Stephen ; Rajiv Selvam ; Sampath Suranjan</i>	

INVESTIGATING THE COMPLEXITY OF COMPUTATIONAL INTELLIGENCE USING THE LEVELS OF INHERITANCE IN AN AOP BASED SOFTWARE	910
<i>S. Senthil Velan</i>	
INTRODUCTION TO FRACTIONAL CALCULUS	915
<i>Rami Alahmad ; Ahmad Abdelhadi</i>	
INDUSTRY 4.0: DEVELOPMENT OF SMART SUNROOF AMBIENT LIGHT MANUFACTURING SYSTEM FOR AUTOMOTIVE INDUSTRY.....	920
<i>Muawia Ramadan</i>	
OPTIMAL DESIGN FO A PORTABLE NUCLEAR MAGNETIC RESONANCE FLOW METER.....	925
<i>Sunil Sonwan ; Mahmoud Meribout</i>	
ANALYZING ANGULAR VELOCITY OF THE HUMAN ARM IN RHYTHMIC WALKING	931
<i>Lanka Udawatta ; Mohammad Alwedian ; Simon Hissem ; Bryan Daniels ; Mouza Almazrouei</i>	
REVIEW OF IMAGE-GUIDED PERCUTANEOUS CORONARY INTERVENTIONS	937
<i>Aseel Alatoom ; Jumana Farhat ; Salam Dhou</i>	
AN EVALUATION OF THE DEVELOPMENT OF FORMATIVE ASSESSMENT STRATEGIES TO ENHANCE STUDENT LEARNING AND ENGAGEMENT	945
<i>Shimna Shafeek ; Vidhya K Viswambaran ; Ben Alex Baby</i>	
ANALYSIS OF DIGITAL UTILITY ENDPOINTS IN SMART GRID USING MODULAR COMPUTING PLATFORM	951
<i>Mohammed Saleh ; Thair Khdour ; Azzeddine Ferrah ; Mahmoud Qasaymeh ; Madeleine Togher</i>	
INNOVATIONS IN MDR THERAPY: ESSENTIAL OIL APPLICATIONS	957
<i>Sik Yang ; Ms Alhosani ; She Lim ; R Akseer ; A Abushelaibi ; Ks Lai</i>	
TRAFFIC CONGESTION IMPROVEMENT ON CLOVERLEAF INTERCHANGE: DUBAI - AL AIN ROAD (E66) AND SHEIKH MOHAMMED BIN ZAYED ROAD (E311)	961
<i>Samir Janho ; Elgaali Elgaali ; Majid Akram</i>	
NOTCH-FILTER ACTIVE DAMPING OF LCL FILTER RESONANCE IN A GRID-CONNECTED INVERTER WITH VARIABLE GRID INDUCTANCE	965
<i>Francis Mulolani ; Ahmed Althobaiti ; Yasser Alamoudi</i>	
A CASE STUDY ON THE AUTHENTIC LEARNING AND ASSESSMENTS IN THE UNIVERSITY EDUCATION.....	971
<i>Jinendrika Weliwita ; Sanjeeva Witharana</i>	
DEEP LEARNING APPLICATION IN MECHATRONICS SYSTEMS' FAULT DIAGNOSIS, A CASE STUDY OF THE DEMAND-CONTROLLED VENTILATION AND HEATING SYSTEM.....	976
<i>Ali Behravan ; Mohammad Abboush ; Roman Obermaisser</i>	
IMPACT OF FLIPPED PHYSICS CLASSES ON THE PERFORMANCE OF ENGINEERING STUDENTS: UNIVERSITY OF SHARJAH CASE STUDY.....	982
<i>Hussein M Elmehdi ; Entesar Z Dalah ; Almehti M. Ibrahim</i>	
EXPERIMENTAL INVESTIGATIONS ON ABRASIVE WATERJET MACHINING OF HYBRIDIZED KEVLAR WITH JUTE FIBER REINFORCED EPOXY COMPOSITE USING TAGUCHI & ANOVA APPROACH.....	987
<i>Sahith Reddy Madara ; Raj N.S. Sarath ; Jerrin Thadathil Varghese ; Chithirai Pon Selvan</i>	
LASER TECHNOLOGY FOR CUSTOMIZING SILICON SOLAR CELLS	996
<i>Douae Nouichi ; Noor Hindawi ; Heba Fares ; Yara Yaghi ; Soliman Mahmoud</i>	
MEASUREMENTS OF RADON CONCENTRATION IN WATER IN THE UNITED ARAB EMIRATES AND THE ASSOCIATED HEALTH EFFECTS.....	1002
<i>Hussein M Elmehdi ; Entesar Z Dalah ; Komyor Bakhronov</i>	
DATA-DRIVEN ANALYSIS OF PRICE CHANGE, USER BEHAVIOR AND WEALTH ACCUMULATION IN BITCOIN TRANSACTIONS	1007
<i>Deepa Pavithran ; Jamal N. Al-Karaki ; Rajesh Thomas ; Charles Shibu ; Amjad Gawanmeh</i>	
VALORIZATION OF WASTE COOKING OIL	1013
<i>Padmaja Vootla ; Maha Majed Ajlan Mohamed Almansoori ; Ayesha Ali Abdullah Othman Alhammadi ; Sara Mahmoud Ali Alhousani ; Fatema Malalla Saif Hasan Alhammadi</i>	
RESEARCH INFORMED TEACHING: A BRIEF ORIENTATION.....	1017
<i>Loraine Charlet Annie ; Fathima Shemim Ks</i>	
ENVIRONMENTAL EFFECTS OF NEW DEVELOPMENTS IN THE COASTAL ZONES OF DUBAI.....	1023
<i>Elgaali Elgaali ; Anf Hanna Ziadat ; Sukina Alzyoud</i>	
BUILDING-INTEGRATED PHOTOVOLTAICS (BIPV) FOR RESIDENTIAL AND INDUSTRIAL PROPERTIES.....	1027
<i>A. Mehravaran ; A. Derhem ; M. Nassereddine</i>	
THERMAL MANAGEMENT OF CONVENTIONAL P V MODULE.....	1033
<i>Divya Shetty ; Arunachala U C</i>	

STATE-OF-THE ART ELECTRICAL MACHINES FOR MODERN ELECTRIC VEHICLES	1038
<i>Yasser A Alamoudi ; Azzeddine Ferrah ; Raghu Panduranga ; Ahmed Althobaiti ; F Mulolani</i>	
DYNAMIC MODEL OF A PROTON-EXCHANGE MEMBRANE FUEL CELL USING EQUIVALENT ELECTRICAL CIRCUIT	1046
<i>Aya Taieb ; Shayok Mukhopadhyay ; Amani Al-Othman</i>	
ADVENTUROUS ARCHITECTURE AND GREEN TECHNOLOGIES	1050
<i>Hadeejathul Ajmeena ; Niva Rana Mahanta</i>	
EFFECT OF GRINDING, POLISHING AND HCL ON SURFACE ROUGHNESS OF LOW CARBON STEEL	1056
<i>Shahid Parapurath ; Mohamed Elkhodbia ; Ebru Gunister</i>	
EFFECTIVENESS OF USING ARDUINO PLATFORM FOR THE HYBRID ENGINEERING EDUCATION LEARNING MODEL.....	1061
<i>Anees Bashir ; Mariam Alhammadi ; Moath Awawdeh ; Tarig Faisal</i>	
UNMANNED AERIAL VEHICLE FOR HUMAN TRACKING USING FACE RECOGNITION SYSTEM.....	1067
<i>Sarath Raj N.S ; Jerrin Thadathil Varghese ; Feni Pandya</i>	
APPLICATION OF OUTLIER DETECTION USING RE-WEIGHTED LEAST SQUARES AND R-SQUARED FOR IOT EXTRACTED DATA	1072
<i>Moath Awawdeh ; Tarig Faisal ; Anees Bashir ; Amjad Sheikh</i>	
LANDSCAPE INTERVENTIONS FOR RESILIENCE AND SUSTAINABILITY IN URBAN WETLAND PARKS: A REVIEW	1078
<i>Niva Rana Mahanta ; Banafsha Rajput</i>	
NANOENGINEERED COMPOSITE MATERIALS FOR WIND TURBINE BLADES	1084
<i>Raghu Panduranga ; Yasser Alamoudi ; Azzeddine Ferrah</i>	
A FRAMEWORK FOR IMPLEMENTING HIGHER-ORDER THINKING SKILLS (PROBLEM-SOLVING, CRITICAL THINKING, CREATIVE THINKING, AND DECISION-MAKING) IN ENGINEERING & HUMANITIES	1091
<i>Omar J. Alkhatib</i>	
PROCESSING AND MECHANICAL PERFORMANCE OF HYDROXYAPATITE-UHMWPE COMPOSITES.....	1099
<i>Abdel-Hamid I. Mourad ; Yaser E. Greish ; Omar G. Ayad</i>	
IMPACT ON HDPE MECHANICAL PROPERTIES AND MORPHOLOGY DUE TO PROCESSING	1104
<i>Edgar B. Mejia ; Abdel-Hamid I. Mourad ; Aisha S. Ba Faqer ; Doaa F. Halwish ; Hour O. Al Hefeiti ; Saleha M. Al Kashadi ; Nizamudeen Cherupurakal ; Mohammad Sayem Mozumder</i>	
SURVEY OF IOT-BASED SMART HOME APPROACHES.....	1109
<i>Abdulla Alhammadi ; Aisha Alzaabi ; Bashayer Almarzooqi ; Suhail Alneyadi ; Zayed Alhashmi ; Maad Shatnawi</i>	
AIRPLANE RELIABILITY STUDY USING GRAPH THEORY BASED MATLAB GUI APPLICATION	1115
<i>Abderrabi Bourezg ; Hamid Bentarzi</i>	
THE IMPACT OF URBAN GREENING AND URBAN GEOMETRY ON THE MICROCLIMATE AT THE NEIGHBORHOOD LEVEL IN HOT ARID CLIMATES.....	1120
<i>Tahani Ahmed Elbondira ; Mona Gamal Eldin Ibrahim ; Manabu Fujii</i>	
INNOVATIVE DESIGN OF HEAT EXCHANGER USING AIRFOIL FINS FOR CONCENTRATED SOLAR POWER PLANTS	1126
<i>Hoor Obaid Alhafeiti ; Halimah Abdullah Almetiri ; Fadi Alnaimat ; Alanoud Ali Alkaabi ; Aysha Khamis Alshamsi ; Bobby Mathew ; Mohammed Ziauddin</i>	
EXPERIMENTAL TESTBED AND PERFORMANCE EVALUATION FOR ROOFTOP SOLAR PV SYSTEM AND GENERATOR SET	1131
<i>Dena Hendriana ; Erikson Ferry Sinaga ; Arko Djajadi Kt</i>	
THE BEHAVIORAL ANALYSIS OF HYBRIDIZED SANDWICH COMPOSITE WITH VARIED YOUNG'S MODULI USING MECHANICAL ANSYS APDL	1139
<i>Jerrin Thadathil Varghese ; Sarath Raj N. S</i>	
DEVELOPMENT OF A SIMPLE AND AFFORDABLE COMPUTER AIDED PROCESS PLANNING (CAPP).....	1146
<i>M.S. Abdul Karim ; Chan Tai Tiong</i>	
STUDENTS' DIFFICULTIES WITH RELATED RATES PROBLEM IN CALCULUS	1150
<i>Nabila A. Azzam ; Manuel Eusebio ; Ruba Miqdadi</i>	
THE EFFECT OF SELF REFLECTION AS AN ASSESSMENT TOOL FOR IMPROVING UNIVERSITIES' STUDENTS PERFORMANCE: CASE STUDY	1155
<i>Molham Chikhalsouk ; Hussni Al Hajjar ; Yasser El-Okda ; Kamel Adref</i>	

AVIATION MRO: A CASE STUDY OF SOCIAL PSYCHOLOGY ELEMENTS OF HUMAN FACTOR AFFECTING WORK PERFORMANCE.....	1161
<i>Kamal Jaiswal ; Serdar Dalkilic ; Seema Verma ; Balgopal Singh</i>	
INTELLIGENT CONTROLLER DESIGN FOR MIMO SYSTEMS USING MODEL-FREE CONTROL AND LMI APPROACHES APPLIED ON A TWIN ROTOR MIMO SYSTEM.....	1171
<i>Younes Al Younes ; Abdelhamid Rabhi ; Hussien Al-Wedyan</i>	
PRODUCTIVITY IMPROVEMENT OF DUCT WORKSHOPS IN THE MODULAR SYSTEMS DIVISION AT BK GULF LLC	1177
<i>Karim Mohd Harbi Sandouka ; Imad Alsyouf</i>	
APPLICATION OF CONTEXTUAL TEACHING AND LEARNING MODEL THROUGH INTERDISCIPLINARY STUDENT PROJECTS – AN APPROACH TO ENHANCING ACCOUNTING AND IT SKILLS	1182
<i>Rachna Banerjee ; Jumana Tarazi ; Moaza Juma Abdulla Ahli</i>	
STABILITY ANALYSIS OF TESLA VALVE BASED NATURAL CIRCULATION LOOP FOR DECAY HEAT REMOVAL IN NUCLEAR POWER PLANTS.....	1190
<i>Rajat A. Chandavar</i>	
ON THE UNICITY OF A SOLUTION IN BIOMECHANICS OF SOFT TISSUES: A NUMERICAL APPROACH	1196
<i>Nizar Harb ; Nadia Labed ; Matthieu Domaszewski ; François Peyraut</i>	
UAE FEMALES IN STEM HIGHER EDUCATION.....	1202
<i>Roudaina Houjeir ; Rula Al-Abbas Al-Kayyali ; Sukina Alzyoud ; Baheia Ahmad-Derweesh</i>	
A SMART DIGITAL SOFTWARE RADIO TRANSCEIVER DESIGN CONCEPT FOR UAV AND AUTONOMOUS VEHICLES APPLICATION.....	1208
<i>Yacine Adane</i>	
REMOVAL OF CD⁺⁺ FROM CONTAMINATED WATER USING BIO-SURFACTANT MODIFIED GROUND GRASS AS A BIO-SORBENT.....	1214
<i>El-Sayed I. Ghaith ; S. Rizvi ; C. Namasivayam ; P.K.S.M Rahman</i>	
WASTEWATER TREATMENT WITH PVC ELECTROSPUN NANOFIBROUS MEMBRANE	1221
<i>Waseem S. Khan ; Najeeb U. Khan ; Muhammad M. Janjua</i>	
DESIGN OF SOLAR PV/FUEL CELL/DIESEL GENERATOR ENERGY SYSTEM FOR DUBAI FERRY	1227
<i>Chaouki Ghenai ; Israa Al-Ani ; Farah Khalifeh ; Tassnim Alamaari ; Abdul Kadir Hamid</i>	
PERFORMANCE ASSESSMENT OF A SOLAR PHOTOVOLTAIC THERMAL HEAT PIPE COLLECTOR UNDER HOT CLIMATE: A CASE STUDY	1232
<i>Oussama Rejeb ; Chaouki Ghenai ; Abdelmajid Jemmi ; Maamar Bettayeb</i>	
FRACTIONAL NONLINEAR SYNERGETIC CONTROL BASED MPPT ALGORITHM FOR PV SYSTEM.....	1237
<i>Abdelbasset Mehiri ; Maamar Bettayeb ; Abdul-Kadir Hamid</i>	
Author Index	

CONFERENCE INVITATION LETTER

February 04, 2019

Dear Dr. Dena,

The organizers of the **International Multi-Conference on Advances in Science and Engineering Technology (ASET'2019)** confirm the paper entitled “*Experimental Testbed and Performance Evaluation for Rooftop Solar PV System and Generator Set*”, author (s): Dena Hendriana, Erikson Ferry Sinaga, and Arko Djajadi KT **has been accepted for oral presentation** by the Program Committee of the Renewable and Sustainable Energy.

We are pleased to invite you to present your paper at our **Renewable and Sustainable Energy International Conference**, as a part of the Advances in Science and Engineering Technology Multi-Conference (ASET'19), to be held 26th - 28th March 2019 at Dubai Men's Campus, Higher Colleges of Technology, Dubai- UAE.

This conference is in line with the UAE National Innovation Strategy and represent hot topics of research in the above-mentioned area, that is of high interest for both the academic and the research communities in the UAE and worldwide. It offers a unique opportunity for academia, researchers, engineers and innovators coming together to present and discuss the latest issues and trends for improvement of brighter future. Your contribution will enrich the conference through enhancing the diversity of perspectives and content represented.

Yours faithfully,



Dr. Azzeddine Ferrah
Chair of the Renewable and Sustainable Energy Sub-Conference (ASET'2019)



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Experimental Testbed and Performance Evaluation for Rooftop Solar PV System and Generator Set

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Abstract



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Adoption of renewable energy sources into daily energy consumption has become both trends and necessity worldwide to cultivate environmentally friendly attitude of living. On top of that, Indonesia was once a member of oil exporting countries, but recently the county has been forced to become a net oil importer due to increasing internal demands. So fossil fuel and electricity are getting pricier. The use of rooftop solar photovoltaics system with a backup system such as a generator set (genset) provides a viable alternative solution. Such a solution is quite popular in Indonesia due to their wide availability and abundance of solar radiation. The underlying questions are: how efficient is such approach, and how can the efficiency be improved. In this paper, first the electric power and energy production of an installed rooftop solar photovoltaics system is studied and possible losses in the system are estimated by comparing daily measurements and PVGIS modelled energy productions. The study reveals that the current system is estimated to have 29% loss that is attributable to the inefficiency in the PV panel, cabling and inverter. Tests on the genset were performed to verify the quality of the AC electricity output and to produce the fuel consumption characteristic of the genset. It was achieved by attaching electric loads to the genset output while inputting a fixed amount of gasoline volume, and recording the running time of the genset for each load. Each test was done for a different electric load. Knowing the running time of the genset, total electrical energy output of the genset could be calculated and its energy efficiency could be calculated. The resultant efficiency curve for the genset used in this study yielded a maximum of 15% of usable electric energy out of 100% of supplied fuel energy. It demonstrated the quite big loss in converting fuel energy to electric energy. Genset producing electricity ideally should be loaded high enough of around 80% of its i...

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Contents

I. Introduction

Indonesia has been forced to become a net oil importer, so fossil fuel and electricity are getting more pricy. Global oil price fluctuates erratically. Therefore, not only must the use of electricity be more efficient, but also must alternative solutions be invented, tested and adopted. Most households in Indonesia use PLN, a name of government's power grid company, as the main source of electrical energy supply. However, the monthly electricity bill keeps increasing steadily due to higher and higher kWh prices. People start to look for alternative sources of electricity simply to reduce their electricity bills and to be less dependent from PLN. To pursue for that, worldwide people start to utilize and convert some natural resources into electrical energy. Global efforts have achieved remarkable technological advances and promising results. Available resources such as sunlight, wind, running water, biomass, etc have been prospected and can readily be converted to usable electrical energy and consumed locally[1]–[15]. Other electrical energy sources such as genset and storage such as battery have been used to fulfill the need for electricity.



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Experimental Testbed and Performance Evaluation for Rooftop Solar PV System and Generator Set

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Abstract—Adoption of renewable energy sources into daily energy consumption has become both trends and necessity worldwide to cultivate environmentally friendly attitude of living. On top of that, Indonesia was once a member of oil exporting countries, but recently the county has been forced to become a net oil importer due to increasing internal demands. So fossil fuel and electricity are getting pricier. The use of rooftop solar photovoltaics system with a backup system such as a generator set (genset) provides a viable alternative solution. Such a solution is quite popular in Indonesia due to their wide availability and abundance of solar radiation. The underlying questions are: how efficient is such approach, and how can the efficiency be improved. In this paper, first the electric power and energy production of an installed rooftop solar photovoltaics system is studied and possible losses in the system are estimated by comparing daily measurements and PVGIS modelled energy productions. The study reveals that the current system is estimated to have 29% loss that is attributable to the inefficiency in the PV panel, cabling and inverter.

Tests on the genset were performed to verify the quality of the AC electricity output and to produce the fuel consumption characteristic of the genset. It was achieved by attaching electric loads to the genset output while inputting a fixed amount of gasoline volume, and recording the running time of the genset for each load. Each test was done for a different electric load. Knowing the running time of the genset, total electrical energy output of the genset could be calculated and its energy efficiency could be calculated. The resultant efficiency curve for the genset used in this study yielded a maximum of 15% of usable electric energy out of 100% of supplied fuel energy. It demonstrated the quite big loss in converting fuel energy to electric energy. Genset producing electricity ideally should be loaded high enough of around 80% of its ideal capacity to further minimize losses.

These findings from experimental setup are useful to consider and where to focus for the next study to gain improved efficiency when combining multi-sources in the context of renewable energy and smart grid. These findings will be applicable in most parts of the world.

Keywords: *Photovoltaics; Solar PV; genset; testbed; measurement*

I. INTRODUCTION

Indonesia has been forced to become a net oil importer, so fossil fuel and electricity are getting more pricy. Global oil price fluctuates erratically. Therefore, not only must the use of electricity be more efficient, but also must alternative solutions be invented, tested and adopted. Most households in Indonesia use PLN, a name of government's power grid company, as the main source of electrical energy supply. However, the monthly electricity bill keeps increasing steadily due to higher and higher kWh prices. People start to look for alternative sources of electricity simply to reduce their electricity bills or to be less dependent from PLN. To pursue for that, worldwide people start to utilize and convert some natural resources into electrical energy. Available resources such as sunlight, wind, running water, biomass, etc can readily be converted to usable electrical energy and consumed locally [1,2,4,5,6,7,11,13,15]. Other electrical energy sources such as genset and storage such as battery have been used to fulfill the need for electricity [1,2,4,11,13].

In another case, many telecommunication stations (BTS) are located away from the city, and the network of electricity from PLN does not reach the sites. In this situation, they need to use genset with a combination of solar panel and battery to power the BTS to cover their continuous operation. Configuration and strategy on utilizing these combinations of power sources have been studied in several references [1,2,4,12,13]. Usually, the use of genset is quite expensive due to the price of the fuel and the difficulty of fuel transport to the site for a continuous operation. Therefore, their strategy is to minimize the use of genset and maximize locally generated energy from available resources.

Below is a brief review of natural resources that offer potential as a source of energy for electrical energy, especially in Indonesia. Sunlight is an abundant source of energy due to country's location around and along the equator. The sunlight is available everywhere, however, its intensity varies between seasons due to weather variations during daylight. Clouds, atmospheric haze, temperature and rains affect the intensity of earth surface radiation [17,19]. The intensity of sunlight depends on the time of the day, with lower intensity dominates in the morning and evening time, and with significantly higher intensity in between during clear sky day. The solar intensity depends on the season, with lower intensity dominates during

raining season and with higher intensity shines during dry season. This variation of radiation intensity undoubtedly will reduce the amount of solar energy reaching the earth surface that can be converted into electricity by the PV panels.

Wind is another source of energy. In general, wind energy in Indonesia is not as high as in northern America or northern Europe. However, it has been surveyed that in some part of Indonesia wind energy has a good potential to be converted to electricity [6,8]. Wind speed and its direction is changing from time to time within the day. To calculate its potential energy, a wind speed graph as a function of time for the whole day of the year is needed. This wind speed graph shows an average for the whole month or even the whole year. With this graph, potential kinetic energy from the wind per unit area can be calculated and estimated for daily, monthly or yearly.

On the other hand, the technology to convert wind to electric energy needs to be adapted to the typical wind speed in Indonesia. Most of wind turbines in the market are rated for high wind speed such as 10 m/s or higher, and this technology is not applicable in Indonesia due to lower wind speed, such as 4-6 m/s. Development of wind turbines optimized for lower wind speed is needed for the application in Indonesia [6,8,9].

Water has been used most extensively to produce electricity. Energy from running water is available in the areas close to rivers or lakes. The conversion of water's potential energy to electric energy can be done in those areas after securing the required license and permit to do so. Blocking a large river flow will create large water area which might displace housing and existing objects in the area.

The other common source of electric energy is a generator set or genset for short. This equipment is available with reasonable price. However, generator sets need gasoline or diesel fuel to run and generate electricity. As the price and transport of the fuel is not cheap, this will increase the operating cost. Test and measurement need be done on a generator set to obtain its electric generation and fuel consumption characteristics, and to find how much the cost to generate electricity per kWh.

Battery is a common apparatus to store electric energy. High capacity battery is still quite expensive and can only store a limited quantity of electric energy. However, its application is essential to enable a continuous electricity delivery to users using some forms of renewable energy sources [4,13]. Optimization of required battery capacity needs to be done to minimize the cost of investment.

II. LITERATURE REVIEWS

A. Solar Panel

The invention of solar cell was started in early 1900s when engineers observed the effect of some material being stroked by sunlight and generated some amount of electric current [3,4]. Significant developments of solar panel occurred around 1970 by many universities and companies. The current technology for solar cell, published by National Renewable Energy Laboratory (NREL) from USA, is shown in the following graph [18].

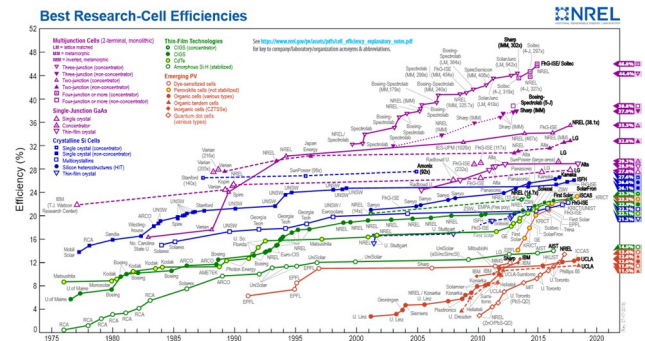


Fig 1. Timeline and development of solar cell efficiencies (source: NREL)

Based on the graph, there are 5 major types of solar cell developments. The first type is multi junction cells. The solar cell efficiency of this type is quite high, 46%, and it is still growing [3,16,18,21]. The challenge for this type of solar cell is that the manufacturing cost is still expensive. The second type is single junction Gallium arsenide (GaAs). Its efficiency is 29%, which is quite high but the cost of this solar cell is very expensive. The most common solar cell is the third type, Crystalline silicon cell. Its highest efficiency is 27%. Poly-Crystalline and Mono-Crystalline solar cells are the main solar panel in the market due to their better price. The price is lower because the manufacturing process for this type of solar cell is easier than other types and with cheaper raw material. Now, researchers are looking for cheaper solar cell and emerging solar cell is made of organic material which is quite popular in universities [22]. However, its efficiency is only 12% and there are still a lot of work to be done to improve it.

Market share for different solar cell types is shown in Figure 2. From this graph, the most popular solar cell in 2010 is Multi-Si or Poly-Crystalline Silicon base solar cell which is holding for around 53% and the second most popular is Mono-Si or Mono-Crystalline Silicon base solar cell which is accounting for around 33% of the market share [16,23]. Both products control 86% of the market share.

B. Photovoltaic Geographical Information System (PVGIS)

PVGIS is a free online solar photovoltaic energy calculator for stand alone or connected to the grid. It calculates the annual, monthly and daily output power and potential electricity generation of solar photovoltaic panels with defined modules tilt and orientation. The area covered by the PVGIS calculator is almost the whole world from America, Europe, Africa and Asia including Indonesia.

PVGIS is utilizing maps representing yearly average of daily total of global irradiation on a horizontal and inclined surface [17]. The data is derived by data enhancement of the Helioclim-1 database [26] which is containing 20-years average, period 1985-2004, see Figure 7. PVGIS contains several calculations:

- Computation of clear-sky global irradiation on a horizontal surface.

- Sky obstruction by local terrain features (hills or mountains) calculated from the digital elevation model.
- Interpolation of the clear-sky index and computation of global irradiation on a horizontal surface.

C. Generator Set

A gasoline generator set is a combination of gasoline internal combustion engine with an electric generator to generate electrical power. Generator sets, or called gensets, are usually used in locations without any connection to power grid, or for emergency power-supply when the grid fails, or for grid support and for exporting to the power grid.

Proper sizing of genset is critical to avoid a shortage of power or over supply of power. Sizing depends on electric demand and complexity comes when the demand is not constant and sometimes unpredictable. Figure 8 shows different kinds of gensets. As a general practice, diesel engines are used up to 50 MW. For higher demand, an open cycle gas turbine is more efficient at full load than an array of diesel engines. The gas turbine is far more compact at comparable capital costs. For regular part-loading, diesel arrays are sometimes preferred to open cycle gas turbines, due to better efficiencies. In a typical household, electric demand is not constant, depending to the condition of the family activity. Generator size of 3000 watt should be sufficient for most of households and we consider this size in this research.

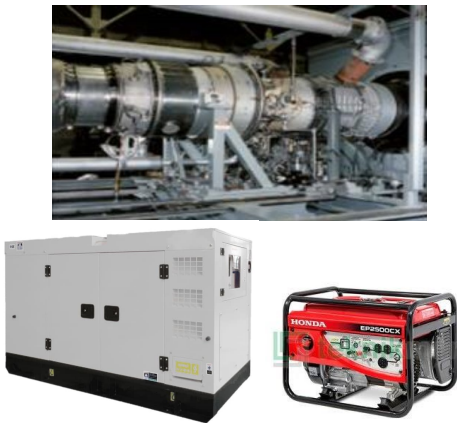


Fig 2. Different kinds of gensets: 12.5 MW gas turbine, 12.5 kW diesel, 2.2 kW gasoline gensets.

III. SOLAR PANEL SYSTEM INSTALLATION AND TEST

In this project, a 2000-watt-peak of solar panel PV system is used as a testbed to evaluate the overall efficiency of the installed system, in comparison to the theoretical analysis from a simulation software tool. The installed PV system consists of 10 pieces of 200-watt solar panels, a cabling system and an On-Grid inverter, as is shown in Figure 9. The location is in Tangerang, Banten, (latitude, longitude: -6.248, 106.606.)



Fig 3. Installation of a rooftop solar panel PV system on site for the test.

The installed system is equipped with a online monitoring system that sends data to the clouds and can be accessed in the internet by the web address www.ginlongmonitoring.com. The monitoring system records the power and energy generated every 5 minutes. From the power generation, the total produced energy is accumulated, recorded, aggregated and displayed by day, by month and by year for ease of monitoring.

Typical graphs of power generation in a day are shown in figure 10 for the recorded data on the 10th and 12th of September 2018. They confirm that power generation starts around 07:00 in the morning and ends around 17:30 in the evening of local time, when the sun rays are shining on the PV panels . Daily power curve is climbing gradually in the morning and dropping down fast in the evening. This could be because of the positioning of solar PV panels at a fixed angle on the rooftop which are facing more to the west and so the sun has more visibility to the panels in the afternoon time until sunset.

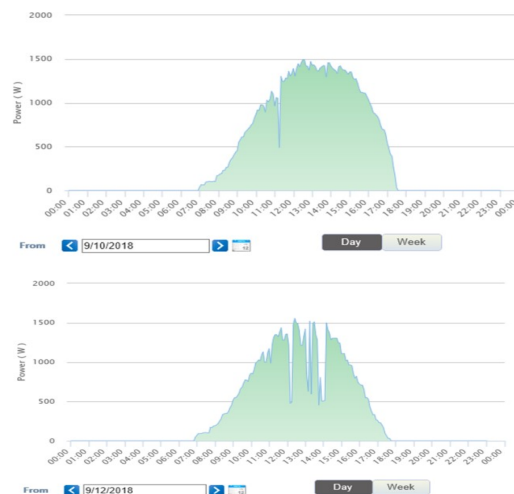


Fig 4. Typical graph of power generation in a day.

The graphs show that during the day time, there were power drops especially for the 12th September data. These power drops were mainly due to clouds or rains that blocked the sun rays resulting in lower electric power generation. Typically the denser the clouds the lower the power generated will be. The longer the time of the clouds blocks along the path of sun rays reaching the PV panels, the longer the time of power drops will be, as can be observed from the graph.

Both graphs show that electric power of the 2000-watt installed capacity can only reach a maximum of around 1500 watt. A quick check to the power generation on any other days, the electric power has never reached 2000 watt, confirming that he maximum power generated was only around 1500 watt. This 80% performance is attributed most likely to the marketed watt-peak as claimed by the vendor of PV panels, whose watt-peak value can only be achieved in idealised testing condition. Further investigation of why the solar panel system never reaches the designed maximum power needs to be planned in a separate study by collecting and using a database based on a large amount of installed PV in many different places in order to compare the claimed watt-peak capacity against the actual power produced. Other factors such as the tilt angle, orientation, shadowing are worth a closer look at.

Daily electric energy generation for June and July 2018 are shown in Figure 11. The amount of electric energy in kWh per day was not constant, depending on the clouds and weather. A heavy rainy and cloudy day on 25 June only produced 1.2 kWh while a very clear day on 1 June produced 9.4 kWh. This evidently indicates that effect of the weather to electric generation is quite significant.



Fig 5. Daily electric energy generation for June and July 2018.

The monitoring system shows that the total electric energy generation on the month of June 2018 was 160 kWh and on July 2018 was 170 kWh. If all days in June were as clear as 1st June day, then the maximum monthly energy generation would be 9.4 kWh x 30 = 282 kWh. And if all days in June were as cloudy as 25th June day, the minimum monthly energy

generation would be only 1.2 kWh x 30 = 36 kWh. As an estimation, the effect of weather on electric energy generation in June gave the energy output of 160/282 x 100% = 57% from maximum monthly energy. The extreme weather whenever all the days in June were as cloudy as 25th June day would give monthly energy output of 36/282 x 100% = 13% from maximum potential produced energy on that day. The range here is 13% to 57%.

Similar study can be done for recorded data on July 2018. Note that data on 16th July was not good because of an internet connection problem. The clearest day in July was 15th July day and it produced 8.1 kWh. Dividing this value by the maximum achievable power of 1.5 kW gives the number of equivalent peak hour with clear sky of of 8.1/1.5 h = 5.4 h for that specific day. Obviously, other days have relatively lower values than 5.4 h. The actual daylight with observale output power is 10 hours / day from the graphs in Figure 10, with a typical half circle shape and not a square shape of power distribution through out the day.

To gain insight about the experimental results based on an actual installed PV system above, the effect of weather to electric energy generation is calculated and simulated in the PVGIS website as briefly reviewed before. In this analysis, we are going to use PVGIS to estimate cable and other system loss in the installed PV panel system by approximating the energy generation in the month of June 2018. After several iterations, we have the following inputs to the PVGIS

- PV technology: Crystalline Silicone
- Installed peak PV power: 2 kWp
- Estimated system losses: 29% (after several iterations to match June energy generation)
- Mounting position: Building integrated (installed on building roof)
- Slope: 30 degree (based on building design)
- Azimuth: 105 derajat (based on building orientation on the map)

The result of PVGIS calculation is shown in the following figure.

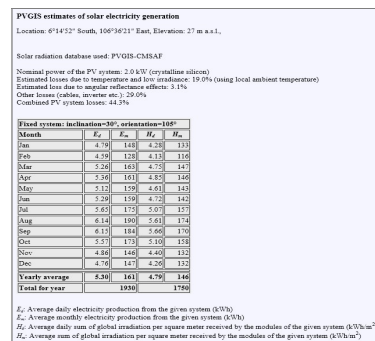


Fig 6. PVGIS calculation result for the project location.

With the cable loss of 29%, the june electric energy production is 159 kWh, which is close to recorded june electric energy production of 160 kWh. Note that July

recorded energy production of 170 kWh has 1 day missing data of 16th July and if that missing day is filled with estimated average of 5 kWh, then the total July production will be 175 kWh and this is the same as calculated July production by PVGIS. Looking at the yearly average from January to December from the PVGIS of 161 kWh, this value is very close to the value from June 2018 of 160 kWh.

This cable loss can be the reason why the solar panel full capacity of 2000 watt is never reached. Subtracting the effect of cable loss to the maximum power, we have $2000 \text{ watt} \times (1.0 - 0.29) = 1420 \text{ watt}$, which is close to maximum value in the daily power graph. The loss can be recovered partially with more efficient inverters, better cabling and improvement of PV efficiency for future installations. Meanwhile the loss of 15.3% are still attributable to the less or uncontrollable environmental factors as has been included in the simulation. This sum up the results obtained from the testbed of solar PV system under study.

IV. GENERATOR SET CHARACTERISTIC STUDY

The generator set or genset used in this project has specifications as follows: Output voltage 220 Volt, Output Frequency 50 Hz, Maximum Output Power 3000 Watt, Rated Output Power 2800 watt, Power Factor 1.0, Starter system electric or manual, Weight 55 kg. The reason for choosing this product is because many households have 2200 VA PLN power connection and it is less than 3000 watt. Ideally, this genset will be used as an electric power back-up in a hybrid renewable energy system for a household which is equipped with other sources such as solar panel, wind turbine and microhydro system.

Two types of tests are performed to verify the main quality of the electricity output. First test is to look into the voltage waveforms of the generated electricity to see the shape and frequency of voltage and compare it to a perfect sinusoidal function of 50 Hz. Second test is to obtain a fuel consumption characteristic of the generator, to calculate efficiency curve of the generator and to estimate the price per kWh on the maximum efficiency for this generator. The voltage waveform generated by this genset can be seen in the Figure 13.

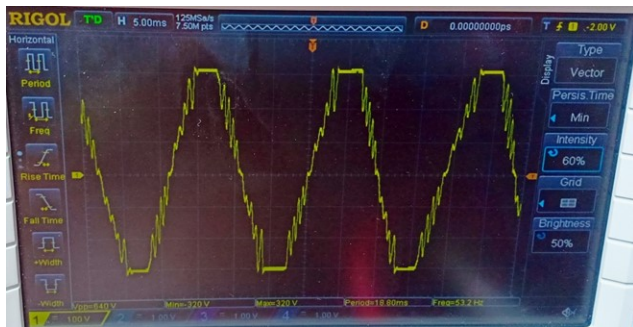


Fig 7. Voltage waveform of the electricity generated by the genset using Rigol DS1074 Digital Oscilloscope.

The graph shows that electrical voltage waveform is not a sinusoidal function but rather a rigid linear function up and

down with linear cut-off in maximum and minimum peak at 320 Volt. The wave contains harmonic waves. Frequency of this wave is 53.2 Hz. To calculate the rms value of this wave, we remove the harmonic waves resulting in a simplified function of the wave as shown in the Figure 14. Wave function is compared to the perfect sinusoidal function.

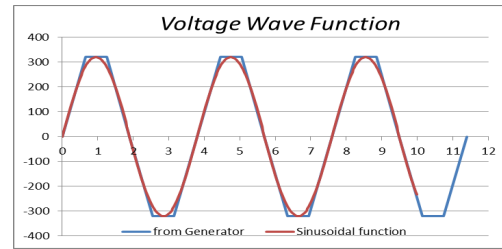


Fig 8. Simplified model of voltage waveform function from genset vs. a sinusoidal function.

The formula to calculate the rms value is

$$f_{\text{rms}} = \lim_{T \rightarrow \infty} \sqrt{\frac{1}{T} \int_0^T [f(t)]^2 dt}$$

Utilizing the formula above, we can get $V_{\text{rms}} = 0.7375$ $V_{\text{max}} = 0.7375 \times 320 \text{ V} = 236 \text{ Volt}$. Note that the constant in front of V_{max} for sinusoidal function is $1/\sqrt{2} = 0.7071$. The voltage function from generator has slightly larger constant in front of V_{max} . Based on this, the deviation from output voltage specification is $(236-220) = 16 \text{ Volt}$, and its error is $16/220 \sim 7\%$. And the frequency deviation is $(53.2-50) \text{ Hz} = 3.2 \text{ Hz}$ and its error is $3.2/50 \sim 6\%$.

Second test is to find generator fuel consumption characteristic and to estimate its efficiency. The test is done by applying different resistive load for the same amount of gasoline, which is 200 ml in this case, and we let the generator runs until it runs out of fuel. In each run, we measure how many seconds the generator runs, how much energy is generated, what are the output voltage and current. To improve test accuracy, each of the case is performed 5 times. Configuration of the test is shown in the following figure.



Fig 9. Test equipment consists of genset, resistive load lamp, electric voltage, current and energy meter and stop-watch.

The following table is the summary of test results. For each run, 200 mL gasoline is used and gasoline energy density is 34.2 mega joule per liter. Therefore, energy content in 200 mL

gasoline is $0.2 \times 34.2 \text{ MJ} = 6.84 \text{ MJ}$. Genset running time is measured by the stop-watch.

No	Gasoline Volume (mL)	Gasoline Energy Content (MJ)	Resistive Load (kW)	Generated Electricity				Genset Energy Efficiency	Genset Running Time (second)	Genset Life Time per Liter Gasoline (minute/Liter)	Gasoline Consumption Rate (Liter/hour)
				V-rms (Vol)	I-rms (Amp)	Total Electric Energy (MJ)	Total Electric Energy (kWh)				
1	200	6.84	0	231.2	0	0.000	0	0.0%	1,035	86.3	0.696
2	200	6.84	0	227.7	0	0.000	0	0.0%	985	82.1	0.731
3	200	6.84	0	223.5	0	0.000	0	0.0%	1,010	84.2	0.713
4	200	6.84	0	222.5	0	0.000	0	0.0%	1,035	86.3	0.696
5	200	6.84	0	224	0	0.000	0	0.0%	1,065	88.8	0.676
average	200	6.84	0	224.8	0.0	0.000	0.0	0.0%	1026	85.5	0.702
6	200	6.84	0.522	223.2	2.34	0.435	0.1209	6.4%	855	71.3	0.842
7	200	6.84	0.513	224	2.29	0.472	0.131	6.9%	880	73.3	0.818
8	200	6.84	0.521	222.9	2.336	0.442	0.1227	6.5%	870	72.5	0.828
9	200	6.84	0.517	222.1	2.328	0.444	0.1234	6.5%	875	72.9	0.823
10	200	6.84	0.523	223.4	2.343	0.414	0.115	6.1%	840	70.0	0.857
average	200	6.84	0.519	223.1	2.327	0.441	0.123	6.5%	864	72.0	0.833
11	200	6.84	1.022	223.2	4.578	0.765	0.2125	11.2%	750	62.5	0.960
12	200	6.84	1.015	222.5	4.563	0.693	0.1925	10.1%	685	57.1	1.051
13	200	6.84	1.024	223.9	4.575	0.721	0.2003	10.5%	711	59.3	1.013
14	200	6.84	1.026	223.6	4.59	0.715	0.1986	10.5%	702	58.5	1.026
15	200	6.84	1.022	223.1	4.58	0.702	0.195	10.3%	690	57.5	1.043
average	200	6.84	1.022	223.3	4.577	0.719	0.200	10.5%	708	59.0	1.018
16	200	6.84	1.941	222.8	8.712	1.084	0.3011	15.8%	565	47.1	1.274
17	200	6.84	1.930	221.5	8.715	0.998	0.2773	14.6%	527	43.9	1.366
18	200	6.84	1.940	222	8.74	1.005	0.2791	14.7%	536	44.7	1.343
19	200	6.84	1.926	221.3	8.705	1.014	0.2816	14.8%	540	45.0	1.333
20	200	6.84	1.933	221.7	8.717	1.004	0.2788	14.7%	533	44.4	1.351
average	200	6.84	1.934	221.9	8.718	1.021	0.284	14.9%	540	45.0	1.333

Fig 10. Test results for different resistive load value.

A resistive load is the same as the generator output power. Electric voltage, current and total energy are measured by the electric power meter. Genset efficiency is defined as a ratio of generated electric energy to the supplied gasoline energy content. Genset life time per liter gasoline is calculated from genset running time in minute divided by gasoline volume in liter. Gasoline consumption rate is calculated from gasoline volume in liter divided by genset running time in hour.

Using results from average data, genset energy efficiency is plotted in the Figure 17. Four data points can be approximated by a quadratic function to represent genset energy efficiency curve.

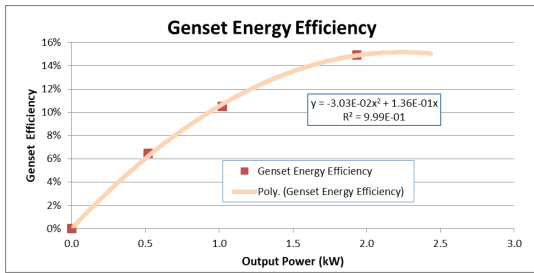


Fig 11. Genset energy efficiency curve as a function of output power.

From the graph, efficiency of genset is zero at zero output power, or in idle condition. The maximum genset energy efficiency is around 15% when output power is around 2.1 kW and the curve starts to drop. Another study [14] on gensets showed maximum efficiency of 16%. This makes sense because when we try to test the genset using 2.5 kW resistive load, genset is running unstable and stop. This indicates that its efficiency declines when the output power is too high. Therefore this quadratic curve seems to be representative characteristic for this genset being evaluated.

Genset energy efficiency is calculated using the following relationship.

$$\text{Genset energy efficiency} = \frac{\text{Output power}}{\text{Gasoline consumption rate} \times \text{gasoline energy content}}$$

From this relationship, the gasoline consumption rate curve is defined from genset energy efficiency curve for given output power.

$$\text{Gasoline consumption rate} = \frac{\text{Output power}}{\text{Genset energy efficiency} \times \text{gasoline energy content}}$$

Output power in kJ/s, gasoline energy content in kJ/liter and genset energy efficiency with no dimension. Applying the trend relation from Figure 17 with output power as independent variable x,

$$\text{Gasoline consumption rate} = \frac{x \times 3600}{(0.136x - 0.0303x^2) \times 34,200}$$

The constant 3600 is the conversion from second to hour. The gasoline consumption rate is drawn in the following figure. Based on this relation, fuel consumption increases at high output power area.

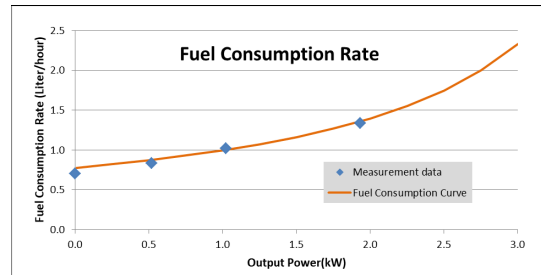


Fig 12. Genset fuel consumption rate curve as a function of output power.

Software renewable energy analysis HOMER (Hybrid Optimization of Multiple Electric Renewables) is using fuel consumption rate curve to be a linear function [10,14]. The curve comparison between the quadratic efficiency curve assumption and linear fuel consumption rate curve assumption are shown in the following figures.

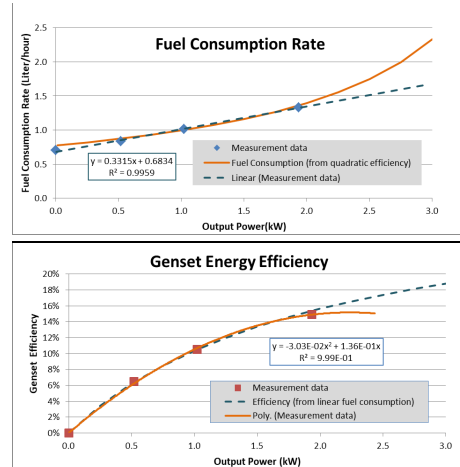


Fig 13. Genset fuel consumption rate curve and energy efficiency curves comparisons: linear efficiency curve (upper) vs. quadratic fuel consumption curve (lower).

Both curves are close in the range of 0 – 2 kW output power, however, the curves are significantly different in high output power area. Different genset machines behave differently close to their maximum rated output power. The machine used in this test behaved unstable at high output

power and therefore the curves associated with quadratic energy efficiency curve seems to be closer to the machine real behavior.

Looking into idle condition, the genset is consuming 0.702 liter/hour to idle. This is the cost for making electricity available using a genset. This fuel consumption rate is equivalent to an internal power of

$$\begin{aligned} \text{Internal Power at Idle} &= \text{fuel consumption rate} * \text{fuel energy content} \\ &= (0.702 \text{ L/hr}) \times (34,200 \text{ kJ/L}) \times (1 \text{ hr} / 3600 \text{ s}) \\ &= 6.67 \text{ kW} \end{aligned}$$

Notice that this internal power at idle is more than twice of the genset rated output power.

We are going to calculate generated electric energy based on fuel price at the highest energy efficiency condition at output power 2.1 kW. Based on the curve, the fuel consumption rate at this condition is 1.45 liter/hour. In this test, gasoline Pertalite is used with unit price Rp. 7800 per liter. The price of electric energy per kWh is

$$\begin{aligned} \text{Price of electric energy} &= \text{fuel consumption rate} / \text{output power} \times \text{gasoline price} \\ &= 1.45 \text{ L/h} / 2.1 \text{ kW} \times \text{Rp.}7800/\text{L} \\ &= \text{Rp.} 5385 / \text{kWh} \end{aligned}$$

This price is quite expensive compared to PLN price which is around Rp. 1500/kWh.

Notice that maximum genset energy efficiency is only 15%. It is quite low compared to other electric generators, such as PLTU with coal fuel where its efficiency could reach around 25-50% and hydro electric generator with its efficiency could reach 90-95%. Larger capacity genset and different brand of genset could have higher energy efficiency.

CONCLUSION

Based on the study on solar panel system and generator set, we can conclude the following

- Maximum power output of the solar panel system is only 75% from the total installed solar panel capacity of 2000 watt.
- Using PVGIS, we can estimate the loss of the solar PV system by matching inputs using actual energy production for the month June 2018. The cable and inverter loss is estimated to be around 29%, which is quite high.
- Cable loss could be the reason why daily maximum power produced to be much less than the capacity power specified. Verification can be done by replacing the cable with a better cable.
- Maximum energy efficiency of the generator set is only 15%.
- Fuel consumption rate at idle for this generator set is 0.702 L/hr, which can be interpreted as internal power of 6.67 kW.
- Although the rated value of the generator set is 2800 watt and its capacity is 3000 watt, the real maximum output power is only 2100 watt (around 70% of its maximum

capacity). If the load is larger, the generator becomes unstable.

- Price to generate electric energy using this generator set is around Rp.5385/kWh. This calculation is based on fuel consumption and price only.
- Generator set is therefore expensive to operate with low efficiency. The usage should be minimized only in emergency situation.

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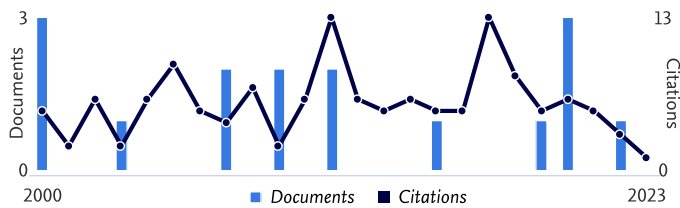
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