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Агамалиев М.М., Алескеров А.А., Ахмедова Д.А.

ТЕХНОЛОГИЯ МНОГОСТУПЕНЧАТОЙ ТЕРМИЧЕСКОЙ ДИСТИЛЛЯЦИИ МОРСКОЙ ВОДЫ С МЕХАНИЧЕСКОЙ КОМПРЕССИЕЙ ПАРА

Азербайджанский государственный университет нефти и промышленности, г. Баку
agamaliyevm@mail.ru

Аннотация

Статья посвящена расчетно-аналитическому исследованию технологии высокотемпературной многоступенчатой термической дистилляции умягченной воды Каспийского моря с механической компрессией пара. Изучено влияние числа ступеней (2÷8), температуры кипения в первой ступени (60÷140^{0}С) и общего температурного напора (10÷40^{0}С) на удельный расход энергии и удельную поверхность нагрева. Показана целесообразность повышения температуры кипения в первой ступени до 120÷130^{0}С при величине выхода дистиллята – 87,5%. Предложена методика оптимизации технологии по минимуму переменной части себестоимости дистиллята.

***Ключевые слова**: Морская вода; Опреснение; Термическая дистилляция; Высокая температура; Повышение эффективности; Оптимизация.*

1. Введение

Рост населения Земли, развитие экономики, изменение климата и ряд других причин привели к дефициту пресной воды во многих странах. Поэтому, как показывает мировая практика, наряду с вопросами рационального использования, менеджмента пресноводных ресурсов, использования сточных вод, становятся актуальными вопросы опреснения морских вод (снижение солесодержания с 12÷45 г/л до 1 г/л и менее). Однако существующие технологии опреснения характеризуются высокими энергетическими и капитальными затратами, что ограничивает их широкое применение [1].

В связи с этим проводятся интенсивные исследования, направленные на повышение эффективности перспективных технологий опреснения, в том числе технологии многоступенчатой термической дистилляции с механической компрессией пара: MED-MVC (Multiple Effect Distillation with Mechanical Vapour Compression) [2].

Согласно этой технологии пар из последней ступени испарительной установки сжимается в специальном компрессоре до параметров, позволяющих использовать его в качестве греющего пара первой ступени. Обычно технология реализуется в температурном диапазоне 70÷50^{0}С, считается рациональной для строительства установок средней производительности: 100÷5000 м^3/сут.

К настоящему времени исследованы различные аспекты технологии MED-MVC. В частности в [3] приведен энерго-эксергетический анализ данной технологии. В работе [4], на примере 4-х ступенчатой установки с температурным диапазоном 72÷50^{0}С приведены результаты сравнительного анализа опреснения океанской воды (35 г/л) с учетом различных схем движения воды и пара. Исследованию влияния числа ступеней (2÷6) и других факторов при прямоточной схеме движении воды и пара на энергетические и экономические показатели процесса посвящено исследование [5].

В работе [6] на примере воды Каспийского моря доказана возможность повышения эффективности традиционной технологии многоступенчатого термического опреснения (без компрессии пара) и снижения себестоимости опресненной воды до 30% при организации процесса в области высоких температур: до 140÷150^{0}C в первой ступени. Исходя из того, что широко используемые для борьбы с накипеобразованием антинакипины при высоких температурах подвергаются термолизу, предлагается проблему сульфатного накипеобразования решать путем предварительного умягчения морской воды методом Na-катионирования, а для снижения интенсивности коррозии металла осуществлять термическую или химическую деаэрации воды. Возможности технологии высокотемпературного многоступнчатого термического опреснения с механической компрессией пара практически не исследовались.

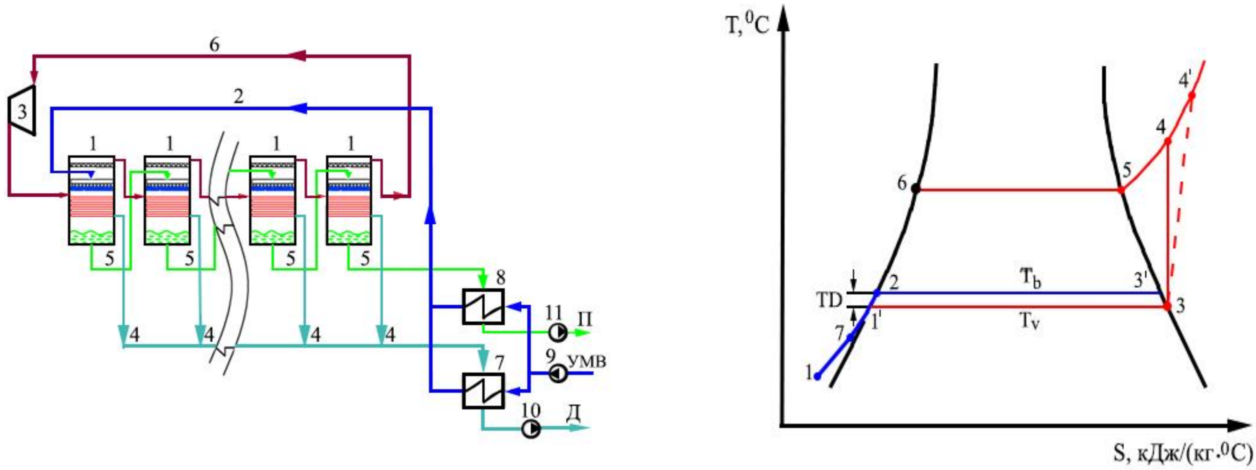
Цель настоящей работы – исследование эффективности технологии высокотемпературного многоступенчатого термического опреснения морской воды с механической компрессией пара на примере воды Каспийского моря.

2. Описание принципиальной схемы и методика проведения исследований

Принципиальная схема исследуемой системы приведена на рис.1.а (блок умягчения не указан). Система включает горизонтально-пленочные испарители (1), компрессор (3), охладитель продувочной воды (7), охладитель дистиллята (8), а также насосы: питательной (умягченной морской) воды (9), дистиллята (10) и продувочной воды (11). Схема питания – последовательная, движение пара и воды – прямоточное. Согласно этой схеме нагретая в теплообменниках питательная вода подается по линии (2) в первую ступень и орошает горизонтальные трубы, внутрь которых поступает пар сжатый в компрессоре (3). Вторичный пар первой ступени используется в качестве первичного пара второй ступени, а продувочная вода (5) – для питания второй ступени. Вторичный пар последней ступени поступает по линии (6) в компрессор (3). Дистилляты ступеней (4) отводятся в качестве опресненной воды.

Термодинамическая сущность процесса отражена на рис.2,б, согласно которой питательная вода в теплообменниках нагревается до определенной температуры (1-2). Далее эта вода в первой ступени испарителя выпаривается при постоянной температуре T_b (2–3^I) с образованием сухого насыщенного пара с температурой T_v (1^I-3). Продувочная вода отводится при температуре T_b. Разность температур T_b-T_v обусловлена температурной депрессией – TD. Вторичный пар последней ступени сжимается в компрессоре, чему соответствует адиабата (3-4), а с учетом термодинамических потерь – политропа (3-4^I). Как видно из графика, сжатый пар оказывается перегретым (4^I-5). Теплота перегрева и скрытая теплота паробразования сжатого пара (4^I-5-6) используются для дистилляции питательной воды в первой ступени при постоянной температуре – T_d. Процессы охлаждения дисиллята и продувочной воды отражаются на диаграмме линиями (6-7) и (2-7), соответственно.

Исследования были выполнены расчето-аналитическим методом и предусматривали разработку математической модели (ММ) системы опреснения с последующим использованием программы C++ для компьютерной симуляции этой модели – изучения влияния основных входных факторов системы, в первую очередь температурного уровня, числа ступеней и температурного напора на совокупность выходных технологических факторов, определяющих эффективность процесса в целом, включая энергетические и капитальные затраты. При этом известные компоненты базовой модели системы принятые из [5,7] дорабатывались с учетом особенностей поставленной задачи: проведения процесса в условиях высоких температур, кратностей упаривания и др.



а) б)

Рис.1. Принципиальная схема (а) и термодинамические диаграмма (б) системы термического опреснения с механической компрессией пара: УМВ –умягченная морская вода, П-продувка, Д –дистиллят

3. Математическая модель системы MED-MVC

Уравнения материальных балансов по потокам и солям, кг/с:

$$M_f = M_d + M_{b.n} \tag{1}$$

$$X_f \cdot M_f = X_{br.n} \cdot M_{b,n} \, , \tag{2}$$

где M_f, M_d *и* $M_{b.n}$ – расходы питательной воды (*feed*), дистиллята (*distillate*) и продувочной воды (*brine*) последней – *n*-ой ступени, соответственно; X_f, $X_{b.n}$ – концентрации солей в питательной и продувочной воде, соответственно, мг/дм^3 (ppm).

В первую ступень испарительной установки подается перегретый пар – Q_1 , кВт:

$$Q_1 = D_1 \cdot \lambda_{d_1} + D_1 \cdot C_{pv_1}(T_{out} - T_{d1}) \, , \tag{3}$$

где D_1 – расход греющего пара первой ступени, кг/с; λ_{d_1}- скрытая теплота паробразования при температуре насыщения, кДж/кг; C_{pv_1}- удельная теплоемкость пара, kДж/kг·^{0}С; T_{out} и T_{d1} – температура поступающег из компрессора (*out*) в первую ступень перегретого и соответствующего сухого насыщенного пара, ^{0}С .

Для остальных ступеней, кВт:

$$Q_i = D_i \cdot \lambda_{d_i} \tag{4}$$

Уравнение теплопередачи для каждой ступени, кВт:

$$Q_i = A_i \cdot U_i \cdot \Delta T_i\ , \tag{5}$$

где A_i – площадь теплообменной поверхности, м^2; ΔT_i – температурный напор, ^{0}С; U_i – коэффициент теплопередачи, кВт/м$^2 \cdot {}^0$С. Для условий высокотемпературного опреснения [7], кВт/m$^2 \cdot {}^0$C:

$$U_i = 0.83 \cdot \left(3 + 0.05 \cdot \left(T_{b_i} - 60\right)\right), \tag{6}$$

где T_{b_i} – температура кипения раствора в каждой ступени, ^{0}С.

Поверхность теплообмена каждой ступени, м^2:

$$A_i = Q_i/(U_i \cdot \Delta T_i) \tag{7}$$

Удельная поверхность нагрева испарителей (*evaporators* – *ev*), м^2/(кг/с):

$$sA_{ev} = \sum A_i\ /M_d \tag{8}$$

ММ теплообменников сводится к выражениям для определения температуры питательной воды после нагрева (T_f), общей температуры охлажденных дистиллята и остаточного раствора (T_0), тепловых нагрузок и требуемой поверхности нагрева охладителя дистиллята (A_d), а также остаточного раствора (A_b) рассчитываемой по данным [7]. При этом температурные напоры определяются как среднелогарифмические.

Сумарная величина удельной поверхности нагрева, м^2/(кг/с):

$$sA = sA_{ev} + sA_d + sA_b \tag{9}$$

Энергетические затраты обусловлены расходом электрической энергии на привод компрессора и насосов. Причем на привод компрессора приходится до 90% общего расхода. Он может быть рассчитан по формуле [4,5], кВт:

$$W_c = m_v \cdot \left(h_{out}^i - h_{in}\right), \tag{10}$$

где m_v – расход пара, поступающего в компрессор, кг/с; h_{in} и h_{out}^i – энтальпия пара на входе (*in*) и выходе (*out*) компрессора, соответственно, кДж/кг (точки 3 и 4 на рис.1,б).

Температура пара сжатого по адиабате (в точке 4), ^{0}С:

$$T_{out}^0 = T_{in} \cdot \left(\frac{P_{out}}{P_{in}}\right)^{\frac{\gamma-1}{\gamma}}\ , \tag{11}$$

где P_{in} и P_{out} – давления пара при соответствующих температурах, кРа, могут быть рассчитаны по формуле приведенной в [5]; γ – степень сжатия пара в компрессоре.

Фактическая энтальпия сжатого пара (в точке 4'), кДж/кг:

$$h_{out}^{i} = h_{in} + (h_{out}^{o} - h_{in})/\eta_c \tag{12}$$

Удельный расход энергии – SEC (specific energy consumption), кВт·ч/м^3:

$$SEC = 1{,}1 \cdot W_c(3{,}6 \cdot M_d) \tag{13}$$

В качестве входных факторов, влияющих на показатели эффективности процесса опреснения умягченной морской воды были приняты: температура кипения в первой ступени – T_{1b} (60÷140^{0}C); число ступеней испарения – n (2÷8); общий температурный перепад – ΔT (10÷40^{0}C). Исследовалось влияние этих факторов на удельный расход энергии – SEC, удельную поверхность нагрева – sA и другие показатели. Фиксированными были приняты: расход дистиллята (опресненной воды) – M_d=1 кг/с; солесодержание умягченной морской воды – X_f =12,6 г/л; температура морской воды – 20^{0}C; кратность упаривания – 8, соответствующая концентрации натриевых солей в последней ступени около 10%, которая рекомендуется для эффективной регенерации Na-катионитных фильтров [6] и обеспечивающая высокий выход дистиллята – 87,5%; степень сжатия пара в компрессоре γ=1,32 и к.п.д. компрессора η_c =0,7.

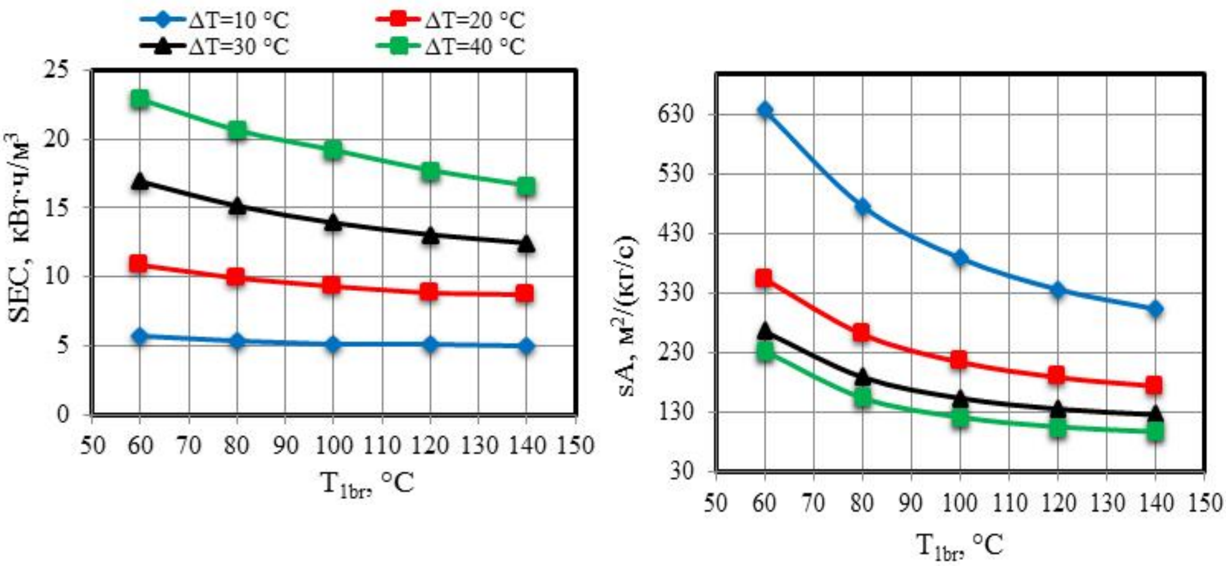
4. Обсуждение результатов исследований

Основные результаты исследований приведены на рис.2-4. Как видно из этих результатов увеличение темературы кипения в первой ступени способствует повышению эффективности процесса как из-за снижения расхода энергии, так и удельной поверхности нагрева. Величина SEC изменяется в пределах 5÷24 кВт·ч/м^3 и влияние температуры кипения заметно повышается с ростом температурного напора: от 0,67 до 6,25 кВт·ч/м^3 (11 и 27% соответственно) (рис.2,а). Такой характер влияния объясняется тем, что с увеличением температуры пара последней ступени снижается удельный объем пара, поступающего в компрессор, соответственно уменьшается расход элекрической энергии для его сжатия.

Удельная поверхность нагрева изменяется в пределах 100÷630 м^2/(кг/с) (рис 2,б) и в исследуемом диапазоне значений температур снижается почти в два раза. При этом, наиболее заметное снижение этого показателя имеет место до температуры кипения 120÷130^{0}C. Снижение величины этого показателя объясняется тем, что с увеличением температуры повышается коэффициент теплопередачи.

Как следует из рис.3 повышение числа ступеней оказывает противоположное влияние на показатели эффективности: удельный расход энергии уменьшается по гиперболическому закону, а удельный поверхность нагрева увеличивается по линейному закону.
При этом существенное снижение энергозатрат наблюдается в области повышения n от 2-ух до 6-ти: почти в 3 раза. Температура кипения в первой ступени оказывает относительно слабое влияние – при $n=6$ энергозатраты уменьшаются на 20%. Рассмотренный характер зависимости SEC от n объясняется последовательным включением ступеней, когда вторичный предыдущей ступени используется в качестве первичного пара последующей ступени. Число ступеней

оказывает существенное влияние и на удельную поверхность нагрева, особенно при низких температурах кипения (рис.3,б), что обусловлено низкими значениями коэффициента теплопередачи.



а) б)

Рис.2. Графики влияния температуры кипения в первой ступени на удельный расход энергии (а) и удельную пеВерхность нагрева (б) при n=6.

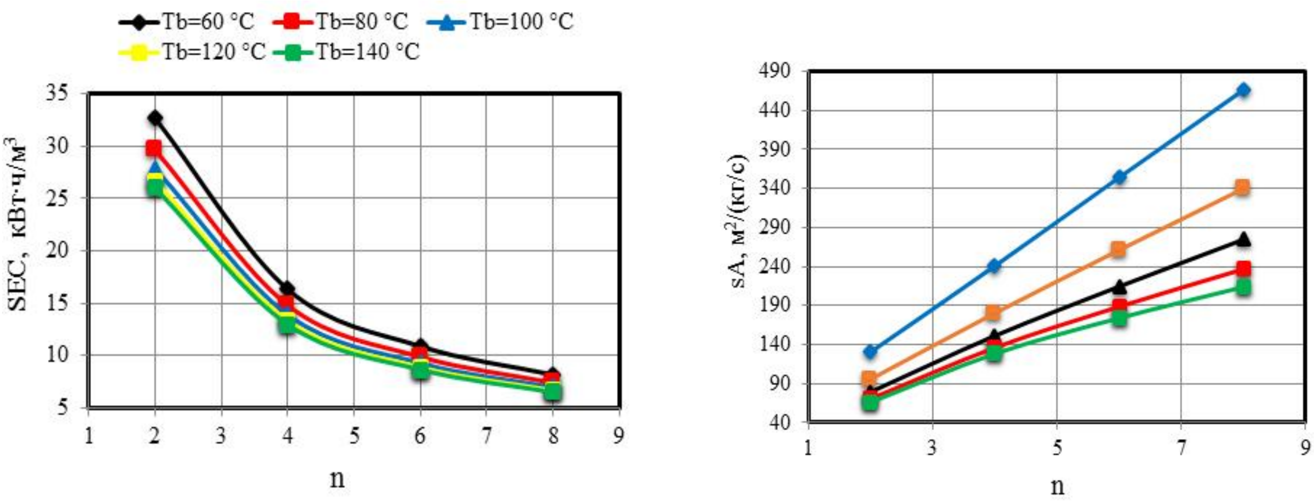


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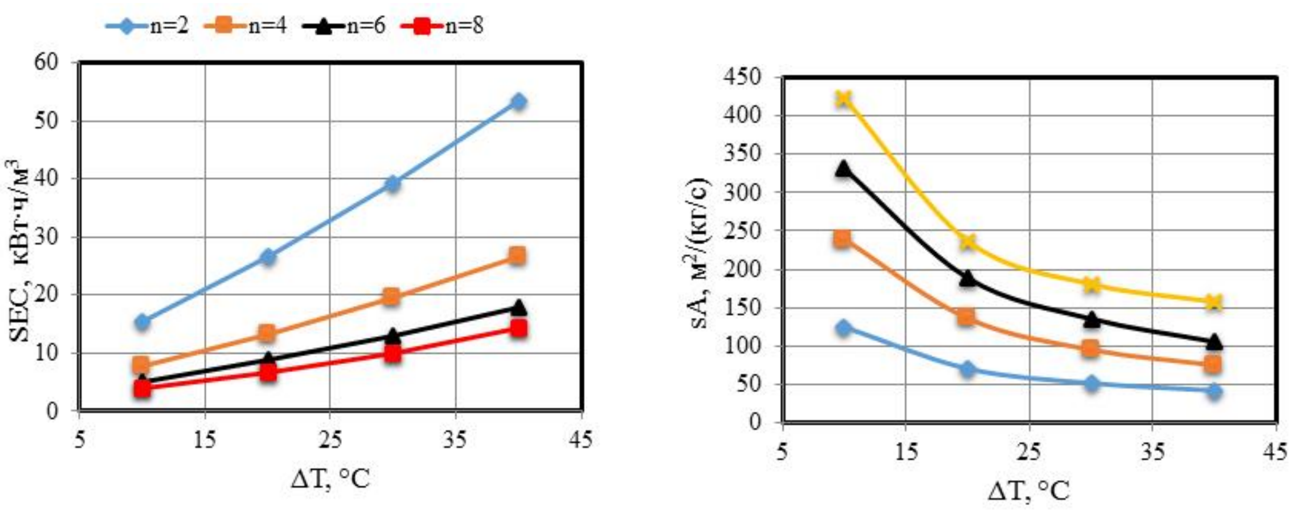
Рис.3. Графики влияния числа ступеней испарительной установки на удельный расход энергии (а) и удельную поверхность нагрева (б) при ΔT= 20 ⁰C.

С увеличением температурного напора и снижением числа ступеней наблюдается рост энергозатрат от 3,8 до 53,3 кВт·ч/м³ (рис.4,а). Влияние температурного напора усиливается с уменьшением числа ступеней: при *n=2* энергозатраты увеличиваются от 15,3 до 53,4 кВт·ч/м³, а при максимальном числе ступеней – от 3,8 до 14,4 кВт·ч/м³. Обратная картина наблюдается по удельной поверхности нагрева (рис.4,б). Из графика следует, что наиболее существенное влияние температуного напора имеет место до величины температурного напора 20÷25^{0}С.



а) б)

Рис.4. Графики влияния температурного напора на удельный расход энергии (а) и удельную поверхность нагрева (б) при Т=120 ^{0}С.

Анализ совокупности полученных результатов показывает, что повышение температурного уровня термической дистиллции однозначно повышает эффективность технологии поскольку снижаются расход энергии и требуемая поверхность нагрева. Но эти зависимости носят нелинейный характер. Что касается двух других факторов (числа ступеней и температурного напора), то повышение их значений оказывает противоположное влияние на показатели эффективности – улучшает один и ухудшает другой. В этой связи возникает необходимость в многопараметрической оптимизации с целью выбора совокупности значений указанных факторов, обеспечивающих минимум такого критерия, как удельные затраты (себестоимость) дистиллята. Для упрощения задачи часто оптимизация проводится по минимуму переменной части ($m_{d,\text{пер}}$), которая является функцией удельных энергозатрат и удельной поверхности нагрева и рассчитывается по формуле [6], дол/м^3 :

$$m_{d,\text{пер}} = 1{,}3a \cdot sA \cdot q_A/\tau \cdot 3{,}6 + SEC \cdot q_E,$$

где a – норма аммортизационных отчислений, a=0,1 [6]; q_A – удельная стоимость поверхности нагрева, дол/м^2; q_E– стоимость электроэнергии, дол/кВт·ч; τ – число часов работы установки в году; 1,3 – коэффициент, учитывающий затраты на текущий ремонт.

Методом Брандона были обработаны результаты вычислительных экспериментов и получены аналитические выражения – $SEC=f(T_{1b}, n, \Delta T)$ и $sA=f(T_{1b}, n, \Delta T)$, что позволило решать задачи оптимизации на основании формулы (14).

$$SEC = (-0{,}1951n^3 + 3{,}8663n^2 - 26{,}893n + 76{,}432)(-3{,}4 \cdot 10^{-3}T_{1b} + \\ +1{,}3412)(-1{,}010^{-5}\Delta T^3 + 9{,}0 \cdot 10^{-4}\Delta T^2 + 0{,}014\Delta T + 0{,}2303), \quad \text{кВт} \cdot \text{ч/м}^3 \qquad (15)$$

$$sA = (37{,}105n + 22{,}621)(-9{,}0 \cdot 10^{-3}T_{1b} + 1{,}9001)(-7{,}0 \cdot 10^{-5}\Delta T^3 + \\ +6{,}8 \cdot 10^{-3}\Delta T^2 - 0{,}2313\Delta T + 3{,}4414), \quad м^2/(кг/с) \quad (16)$$

Расчеты показывают, что оптимальные условия организации процесса в значительной степени зависят от местных условий: стоимости электроэнергии и металла. В таблице приведены результаты расчетов оптимальных условий, выполненных методом сканирования – упорядоченного перебора вариантов для диапазона изменения $q_E = 0{,}03 \div 0{,}07$ дол/ кВт · ч и q_A= 100÷300 дол/м^2. Как следует из результатов расчетов, для рассматриваемых условий, оптимальным условиям соответствуют высокие значения температуры кипения и числа ступеней в сочетании с низкими значениями температурного напора (10÷25 ^{0}С). При этом удельный расход электроэнергии находится на уровне 5÷7 кВт· ч/м^3, что сопоставимо с энергозатратами наиболее экономичного обратноосмотического метода опреснения.

Оптимальные условия высокотемпературной технологии MED-MVC

Показатели	q_E, дол/кВт·ч								
	0,03			0,05			0,07		
	q_A, дол/м^2								
	100	200	300	100	200	300	100	200	300
$m_{d,пер}$, дол/м^3	0,28	0,39	0,48	0,38	0,51	0,61	0,45	0,59	0,73
n	6	8	8	8	8	8	7	8	8
T_{1b}, ^{0}С	130	130	130	125	130	130	130	130	130
ΔT, ^{0}С	10	20	25	15	20	20	10	15	15
SEQ, кВт· ч/м^3	4,72	6,04	7,55	4,76	6,04	6,04	4,17	4,66	4,66
sA, м^2/(кг/с)	273	199	167	277	199	199	314	259	259

5. Заключение

Возможность предотвращения образования накипи сульфата кальция на теплообменной поверхности испарителей, при термической дистилляции морской воды умягченной методом Na-катионирования, создает предпосылки для повышения эффективности технологии MED-MVC путем организации процесса при высоких температурах в первой ступени (130÷140^{0}С вместо практикуемых обычно 70÷80^{0}С) и кратностях упаривания (8÷10 вместо 2÷2,5). В результате, при числе ступеней равном 6-ти, удельный расход энергии снижается, в среднем до 20%, удельная поверхность нагрева – на 50%, а выход дистиллята (конверсия) повышается от 50÷60% до 87,5÷90%. Повышение числа ступеней испарительной установки (2÷8) и температурного напора (10÷40^{0}С) оказывают противоположное влияние на показатели эффективности технологии. Поэтому возникает необходимость решения оптимизационной задачи по минимуму переменной части себестоимости дистиллята как функции от трех вышеуказанных факторов. Соответствующие расчеты показывают, что при стоимости электроэнергии, в среднем, 0,05 дол/кВт·ч и поверхности нагрева 200 дол/м^2 оптимальные условия достигаются при высоких значениях температуры кипения и числа ступеней, а также низких значениях температурного напора.

Следует отметить, что в качестве альтернативы, технологии Na-катионирования может быть использована разработанная в последние годы более простая технология нанофильтрационного умягчения [8]. Однако, она не обеспечивает столь глубокого удаления накипеобразующих как Na-катионирование, вместе с тем позволяет наряду с ионами жесткости снижать концентрацию сульфат-ионов. Поэтому одним из направлений дальнейших исследований является изучение эффективности технологии MED-MVC с предварительным нанофильтрационным умягчением морской воды.

Полученные результаты представляют интерес для прикаспийских республик, в которых существует проблема дефицита пресной воды: Азербайджан, Казахстан, Туркменистан.

Список использованной литературы

1. *Youssef P.G., Al-Dadah R.K., Mahmoud S.M.* Comparative Analysis of Desalination Technologies. The 6th International Conference Applied Energy – ICAE 2014, p.2604-2607.

2. *A.Nafey, H.Fath, A.Mabrouk.* Thermoeconomic design of a multi-effect evaporation mechanical vapor compression (MEE–MVC) desalination process, Desalination, 230 (2008) 1-15.

3. *M.L. Elsayed, O. Mesalhy, R.H. Mohammed, L.C. Chow*. Performance modeling of MED-MVC systems: Exergy-economic analysis, Energy, 166, 2019.

4. *Abdelkareem Mohamed*. Dynamic Behavior and Performance of Different Types of Multi-Effect Desalination Plants" (2019). *Electronic Theses and Dissertations*. 6336. https://stars.library.ucf.edu/etd/6336

5. *Muhammad A. J., Syed M. Z.* Design and analysis of a forward feed multi-effect mechanical vapor compression desalination system: An exergo-economic approach. Energy 140 (2017) 1107-1120.

6. *Фейзиев Г.К.* Высокоэффективные методы умягчения, опреснения и обессоливания воды. Изд. 2-е, Баку: «Тахсил» ТПП, 2009, 442с.

7. *El–Dessouky H.T., Ettouney H.M.* Fundamentals of Salt Water. Desalination ELSEVER, Amsterdam, Tokio, 2002, 691 p.

8. *Dong Zhou, Liying Zhu.* Development of lower cost seawater desalination prosses using nanofiltration technologies – A review. Desalination, 376, 2015, p.109-116.

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Prospects for the use of biomass in Azerbaijan

Azərbaycanda biokütlədən istifadənin perspektivləri

Перспективы использования биомассы в Азербайджане

Babayeva S. Sh., Shikhkarimov N. N.

Azerbaijan Oil and Industry State University

Annotation

A classification of biogas plants has been analyzed, the features of their functioning have been disclosed, a map of the processes of a biogas plant has been developed on the basis of a system and process approach. We have carried out research proposed the optimal scheme of a biogas plant for effective functioning in the conditions of Azerbaijan.

Key words: biogas, methane, classification, process efficiency, installation scheme, systems approach.

Babayeva S. Ş., Şıxkərimov N. N.

Azərbaycan Dövlət Neft və Sənaye Universiteti

Annotasiya

Bioqaz qurğularının təsnifatı analiz edilmiş, işləmə xüsusiyyətləri açıqlanmış, sistematik və proses yanaşması əsasında bioqaz qurğularının proseslər xəritəsi hazırlanmışdır. Azərbaycan şəraitində səmərəli işləməsi üçün bioqaz qurğusunun optimal sxemini təklif edən tədqiqatlar aparılmışdır.

Açar sözlər: bioqaz, metan, təsnifat, proses səmərəliliyi, quraşdırma sxemi, sistem yanaşması.

Бабаева С. Ш., Шихкаримов Н.Н.

Азербайджанский Государственный Университет Нефти и Промышленности

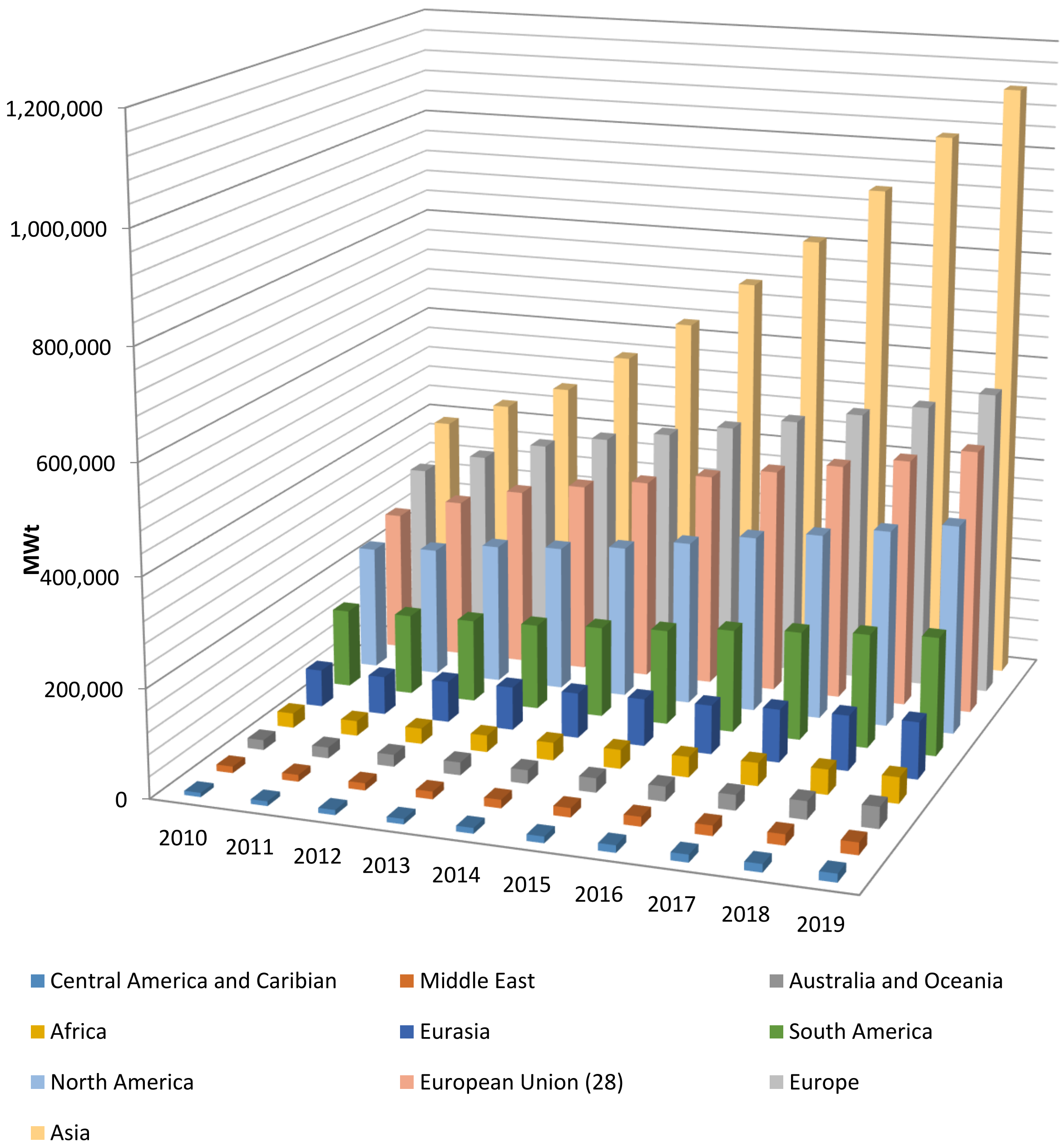
Аннотация

Разработана классификация биогазовых установок, раскрыты особенности их функционирования, на основе системного и процессного подхода разработана карта процессов биогазовой установки. Нами проведенных исследований предложена оптимальная схема биогазовой установки для эффективного функционирования в условиях Азербайджана.

Ключевые слова: биогаз, метан, классификация, эффективность процессов, схема установки, системный подход.

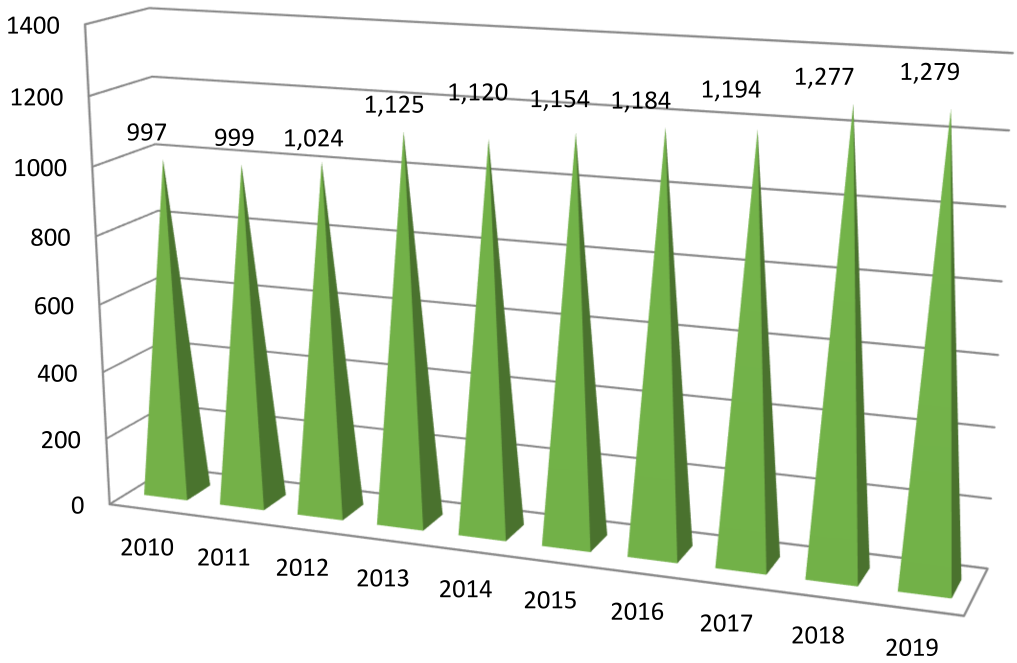
INTRODUCTION

As human society developed, so did industry and agriculture, and the need for energy increased. One of the global problems facing humanity today is the uninterrupted use of fuel resources. Traditional energy sources such as oil, natural gas and coal are depleted, polluting the environment and expensive. In contrast, alternative energy sources are environmentally friendly and inexhaustible. Therefore, demand for alternative energy continuously increases. Till the end of 2019, the world's renewable energy capacity increased by 2537 gigawatts (GW), 176 GW more than in the 2018. [1- 2]. The "The world's renewable energy capacity" graph (Pic. 1) illustrates renewable energy capacities of world countries from 2010 to 2019. Leader of this area is Asian countries.



Pic.1. The world's renewable energy capacity

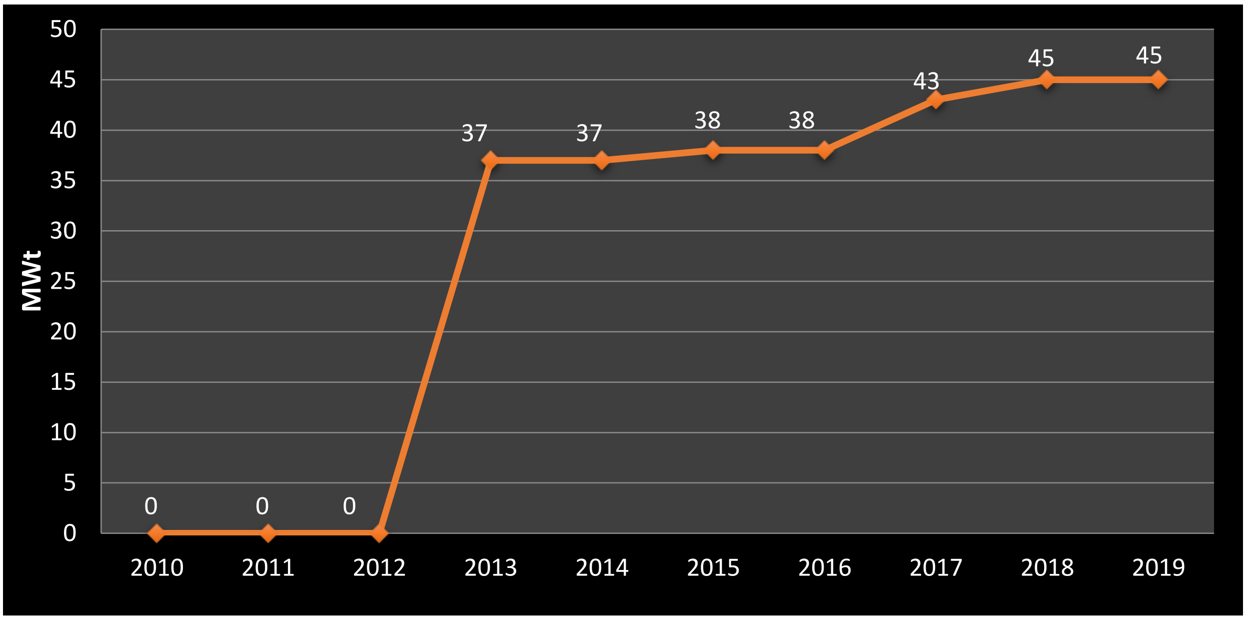
As it is in the world, Azerbaijan also has a huge potential for renewable energy sources and there is political will for using it everywhere (Pic. 2). The use of renewable energy sources leads to an increase in the level of reliability of power supply, reduction in total costs of electricity generation, savings natural resources, creating new jobs and positively affecting environmental protection. Currently, water, wind, sun, and biogas energy are used as an alternative energy resource in Azerbaijan.



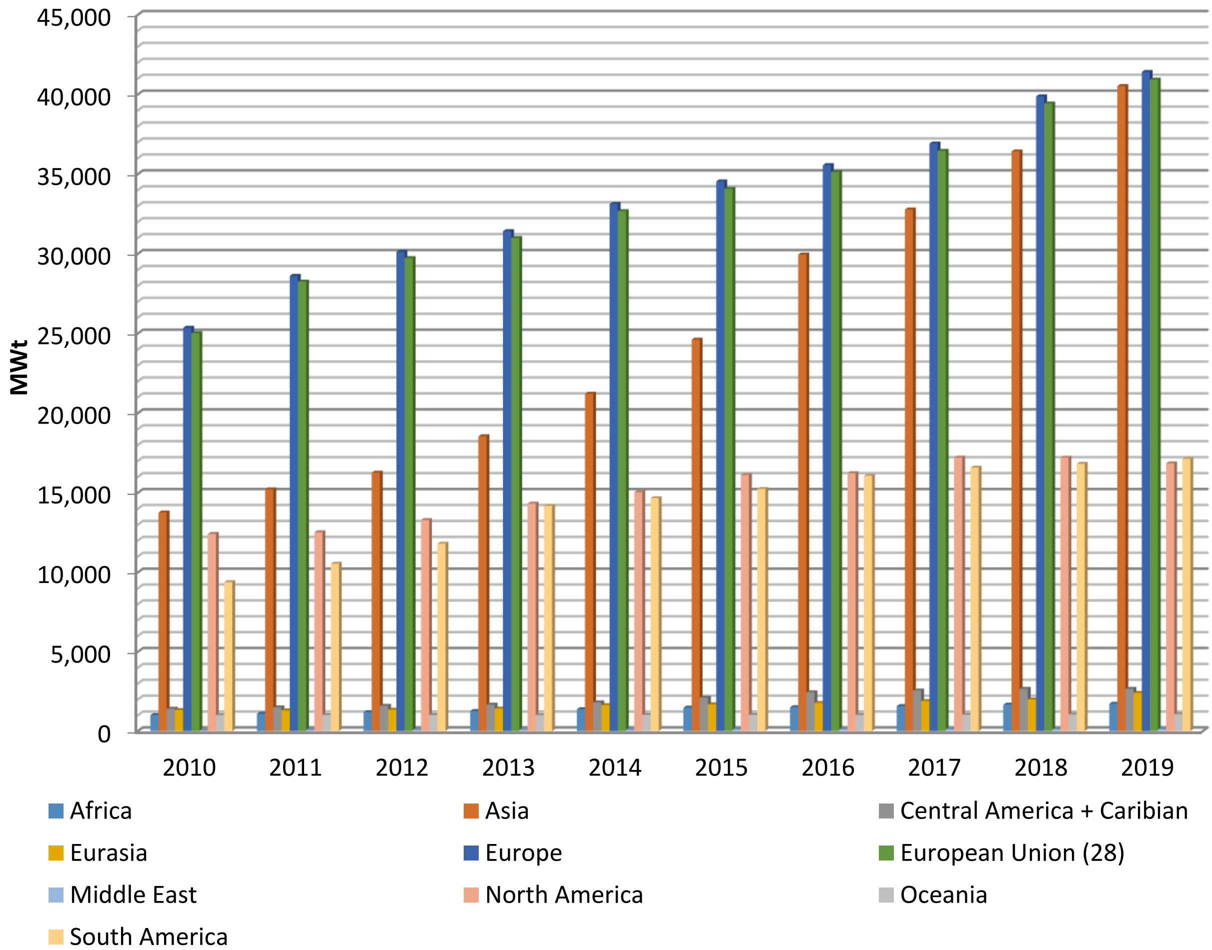
Pic.2. Renewable energy capacity of Azerbaijan

Biomass is also an alternative energy source. There are several energy sources of biomass in Azerbaijan: industrial waste, forestry and woodworking waste, agricultural crops, waste of organic compounds, waste of household and communal services, production waste territories contaminated with oil and oil products. According to research, most of the waste consists of biomass products in all sectors of the economy.

It is possible to obtain gas, liquid and solid biomass, which are used in the production of electricity from these biomass substances. Thus, more than 2.0 million tons in Azerbaijan, solid and industrial wastes were discharged annually into the neutralization zones. Recycling of solid and industrial waste allows to partially eliminating the difficulties with heating public buildings in Baku and large industrial cities of the country. Bioenergy is one of alternative energy resources. The Azerbaijan’s and world countries’ bioenergy capacities from 2010 to 2019 are shown in Pic. 3 and 4, respectively.



Pic.3. Azerbaijan's bioenergy capacity



Pic.4. The world's bioenergy capacity

LITERATURE REVIEW

For achievement in this area, scientific research should be done. In modern science, production of biogas is of great importance for obtaining biofuels, heat, electrical energy, of fertilizers, to prevent emissions of methane into the atmosphere, and can also be used as an automotive fuel [1-2]. Some gases including methane has an effect on the greenhouse effect in 23 times stronger e e than CO_2, and stored in an atmosphere of 12 years, capturing methane - the best way to prevent short-term global warming. Fertilizers obtained in the bioreactor reduce the amount of chemical fertilizers used.

Biogas plants can work as a treatment plant at farms, poultry farms, distilleries, sugar factories, meat processing plants and replace a veterinary and sanitary plant, i.e. carrion is disposed of in biogas instead of meat and bone meal production [3 - 8].

The leading place in the production of biogas use and by comparative indicators belongs to Denmark among industrialized countries - biogas occupies up to 18% of its total energy balance. In absolute terms (in terms of the number of medium and large installations), Germany takes the leading place - 8 million units. In Western Europe, slightly less than half of all poultry farms are heated with biogas [5]. Potential production in Russia biogas is to 72 billion cubic meters per year, while in Azerbaijan the production of biogas is more than 57 million cubic meters^3 per year. With the development of industrial and agriculture, in Azerbaijan, new opportunities are opening up for the production of thermal and electrical energy from biological resources. Biomass is a source of industrial fuel emissions, waste from wood processing, agriculture, agriculture, oil-contaminated soil. They are a source of energy. The republic produces 2 million tons of solid waste annually. In large cities, public buildings can be heated by utilization of solid wastes. Today, in Azerbaijan, more than 200 landfills are working for waste. Their total area is 900 hectares. Methane emissions from landfills in large cities, respectively: in Baku - 42.8 million m^3, in Ganja - 7.2 million m^3, Sumgait - 6.9 million m^3 and etc. [10]. In these cities, a small power plant can be built for power generation. So far, in the country the number of projects that uses biomass is limited. The advantages of biogas technology are: use of renewable, local plant and animal raw materials for energy production; the possibility of using still economically unused plants (or their parts); the possibility of recycling organic waste for energy production; decentralized power supply without many kilometers of communications; reduction of greenhouse gas emissions such as methane (CH_4), laughing gas (N_2O), carbon dioxide (CO_2) into the atmosphere; only that amount of CO_2 is released that was assimilated by plants during growth (closed cycle of CO_2), methane is not released into the atmosphere; improving the quality of fertilizer compared to untreated manure, reducing the intensity of odor and alkalinity when applied to the soil, faster absorption of nutrients by plants compared to untreated manure; during fermentation, the number of pathogenic microbes and weed germination are reduced; saving fertilizers and pesticides, the fermentation residue is an effective and environmentally friendly substitute for mineral fertilizers, the energy contained in one cubic meter of biogas is equivalent to the energy of 0.6 m^3 of natural combustible gas or 0.74 liters of oil, or 0.65 l of diesel fuel, or 0.48 liters of gasoline.

When using biogas, fuel oil, coal, electricity and other energy carriers are also saved. The introduction of biogas plants improves the ecological situation at livestock farms, poultry farms and adjacent territories, prevents harmful runoff into gullies, lakes, ravines, into small and large rivers, where, as a result, the habitat improves [9].

Obtaining biogas and its further use is a complex process, which is influenced by many factors, each of which is impossible to evaluate separately In this case, a set of many elements is needed that are in essential relationships and connections with each other and form a certain integrity, unity. This is an integral set of elements interacting with each other, there are significant connections between the elements of the system, which, with natural necessity, determine the integration qualities of this system. To form a system, it is necessary to provide ordered connections, i.e. to create a specific organizational structure, consisting of interconnected objects and subjects of management, implementing the target function of the system.

Based on the analysis [3, 4, 7, 9, 10], it can be concluded that it is most important to increase the efficiency of biogas plants in the context of improving the technical indicators of the biogas production process, as backbone elements of the system. The rest must be considered when conducting research as restrictive.

MAP OF BIOGAS PLANT PROCESSES

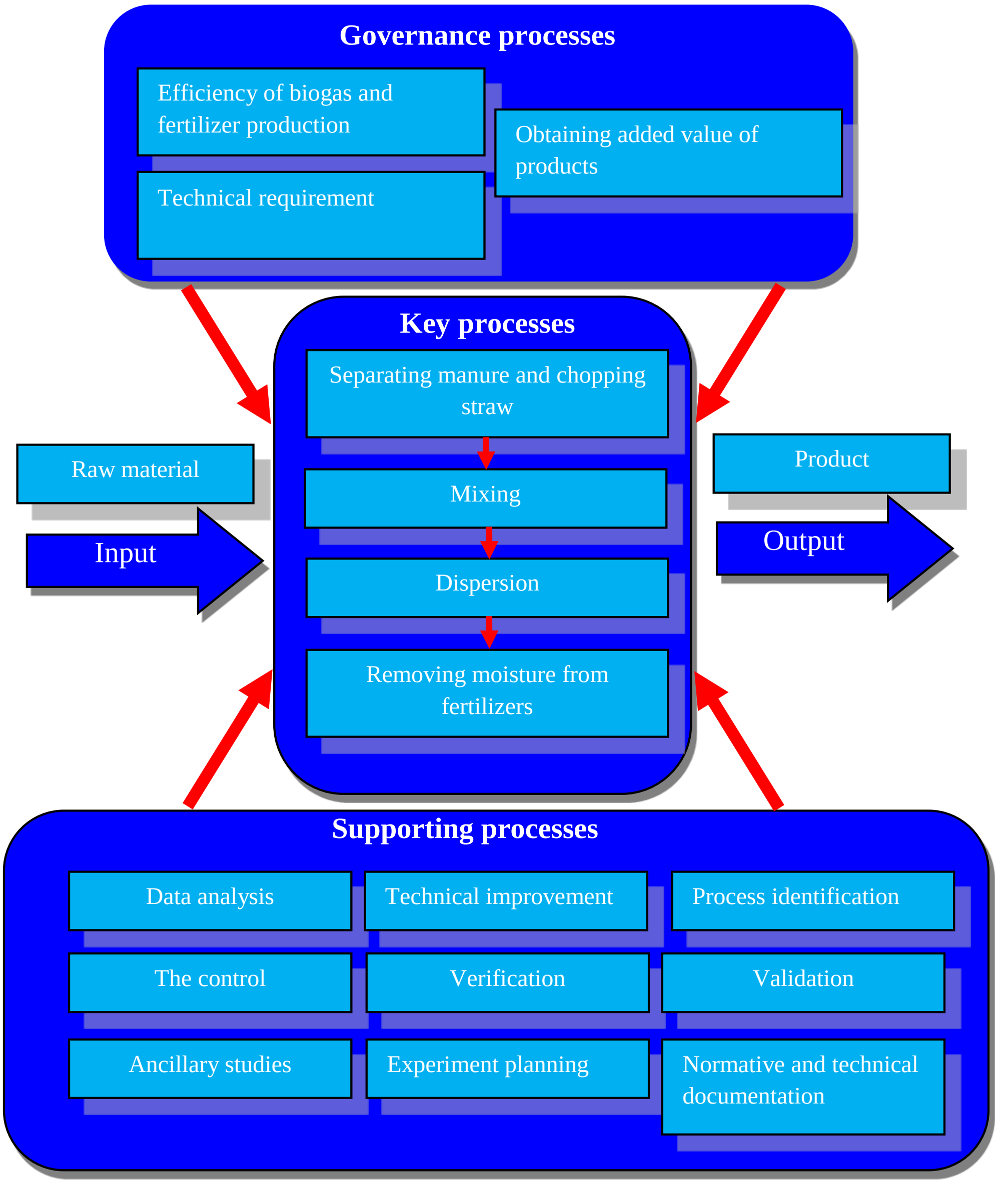
The received organic raw materials contain a large number of materials of different physical and mechanical composition: animal manure, straw, foreign objects. Straw is a bedding material, rich in fiber and a poor raw material for methane production; in a bioreactor, it flakes from manure, floats to the surface and forms a layer that prevents gas release. In the process of obtaining biogas, it is necessary to pre-separate the viscous or loose, depending on the moisture content, manure from straw, chop the straw before entering the bioreactor, and, if necessary, purify it from impurities. Thorough grinding of organic materials supplied for processing, especially straw, increases the fermentation rate and shortens the processing time, mixers of various designs are used to ensure homogeneity and destruction of the gas-tight crust, the selection and substantiation of their optimal design and operating parameters is a reserve for increasing the amount of methane produced. Dispersion also improves homogeneity, and dispersed grinding increases the efficiency of the biogas plant.

For effective modeling, it is necessary to use the process and systems approach of the international system. The desired result is achieved more effectively when activities and associated resources are managed as a process.

Continuous improvement includes improvement in small steps and breakthroughs, periodic assessments of compliance with established excellence criteria to identify areas for potential improvement, and continuous improvement in the efficiency of all processes.

The well-functioning of the system must define and manage numerous interrelated processes that use resources and are managed to transform inputs into outputs, while often the output of one process forms the direct input of the next.

Pic. 5 demonstrates a map of biogas plant processes. Control processes are aimed at its organization, purpose and technical requirements. The quality of the process lies in the receipt by the product of added value, reflecting economic efficiency. The processes are aimed at maintaining, monitoring, adjusting and preventing possible deviations from regulatory requirements.



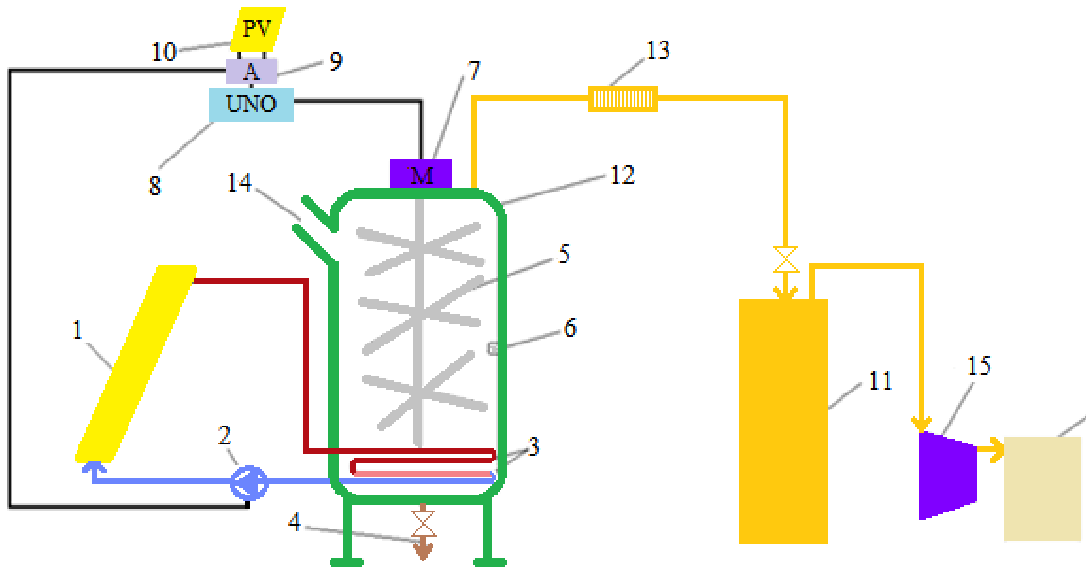
Pic.5. Map of biogas plant processes

The description of the process should take into account the components necessary for its proper functioning: define the boundaries of the process; establish the requirements for it; identify input and output streams; determine the main indicators. The development of equipment for biogas plants is associated with the use of a large amount of information; the development of methods for the design of large and complex systems requires the use of system analysis.

The main goal of the approach to the process is continuous improvement, which is based on the development of a new structure of models, focus on meeting consumer needs, analysis of data on the functioning of the system, maintaining a long-term stable state of the system as a whole and its elements [9].

BIOGAS PLANT TECHNOLOGICAL SCHEME

The general scheme of the technological process of functioning of the biogas plant which is offered by authors of this article is shown in pic. 6.



Pic.6. General scheme of the technological process of functioning of the biogas plant
1 - solar collector; 2 - circulating pump ; 3 - heat exchanger; 4 - discharge opening ; 5 - mixer; 6 - thermocouple; 7 - gear motor; 8 - arduino (for automatic control system) ; 9 - accumlator; 10 - solar battery ; 11 - gas holder ; 12 - bioreactor housing ; 13 - gas filter ; 14 - loading hole; 15 - compressor; 16 – consumer.

Pic. 6 shows a diagram of a stand-alone biogas plant. The plant consists of three main components: 1) The bioreactor, equipped with an electric motor for mixer; 2) Solar collector for biomass heating; 3) Solar panel to meet the electricity demand (250 W). Another feature of the device is its automation system. This system takes into account the technological process (pump operation and maintenance, interruption and interruption of the mixer motor and the activation and maintenance of the electric heater) without human intervention.

Thus, the natural-geographical status and favorable climatic conditions of Azerbaijan not only positively affect the agricultural sector, but also contribute to the improvement of the bioindustry. Biogas can be produced by using annual waste from agriculture and animal husbandry as a biomass resource, which can reduce the consumption of traditional energy sources and minimize environmental pollution. These key factors are useful when designing small biogas plants, especially in mountainous rural areas of Azerbaijan.

The main advantage of the dedicated biogas plant compared to others is the programmable automatic control system, which can operate in round wefts without human intervention. Given the autonomy of the proposed biogas technology and the available climatic conditions, it can be assumed that effective results can be obtained.

RESULTS

1. According to analysis of [1-10] literatures, both alternative and bioenergy potentials in the world and in Azerbaijan have been studied over the 2010 - 2019 years. Based on IRENA 2020's data, graphs are plotted to show the distribution of the world's and Azerbaijan's

alternative energy potential over the years. As a result, the use of alternative energy in the world and in Azerbaijan is lower than its potential. In addition, bioenergy sources in Azerbaijan are indicated.

2. A classification of biogas plants has been developed; the features of their functioning have been disclosed.
3. On the basis of a systematic and process approach, a map of biogas plant processes has been developed.
4. We have carried out research proposed the optimal scheme of a biogas plant for effective functioning in the conditions of Azerbaijan, and in the article, this scheme has been offered by authors.

References

1. IRENA (2020), Renewable capacity statistics 2020 International Renewable Energy Agency (IRENA), Abu Dhabi
2. Aydin, U. 2019. Energy Insecurity and Renewable Energy Sources: Prospects and Challenges for Azerbaijan. ADBI Working Paper 992. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/energy-insecurity-renewable-energy-sources-challenges-azerbaijan
3. Dreher Teal M. Effects of chlortetracycline amended feed on anaerobic sequencing batch reactor performance of swine manure digestion // Bioresource technology. V. 125. Pages 65-74.
4. Барков В.И. Исследование динамики выделения биогаза в анаэробных условиях // Вестник с.-х. науки Казахстана. №9 (2012), С. 90-94.
5. Nicolae Scarlat , Jean-François Dallemand, Fernando Fahl, Biogas: Developments and perspectives in Europe // Renewable Energy Volume 129 (2018), pages 457-472
6. UNECE // Summary the Russian Federation and CIS countries on Development of Renewable Energy, 2011
7. Triolo Jin M. Biochemical methane potential and anaerobic biodegradability of non-herbaceous and herbaceous phytomass inbiogasproduction // Bioresource technology. V. 125. Pages 226-32.
8. Bulkowska K. Optimization of anaerobic digestion of a mixture of Zea mays and Miscanthus sacchariflorus silages with various pig manure dosages // Bioresource technology. V. 125. Pages 208-16.
9. Fulford, D., Small-scale rural biogas programmes: A handbook, Practical Action Publishing, Rugby, 2015.
10. Алиев Р.А., Исмаилова Г.Ф., Зеленая экономика» в Азербайджанской Республике: предпосылки и направления развития // НАУКОВЕДЕНИЕ № 6 , 2015.

Babayeva Sevinc Shulan – Candidate of Technical Sciences (Ph.D), Associate Professor in “Energy production technologies”. In 1986, she graduated with honors from the Azerbaijan Institute of Petroleum and Chemistry, Faculty of Energy with a degree in “Industrial Thermal Power Engineering”.
She defended his dissertation on the “Coefficient of thermal conductivity of three-component electrolyte solutions at high pressures and temperatures” topic. The main scientific works cover the topics about the theoretical foundations of thermal engineering, thermal energy, alternative energy sources. She is currently an associate professor of “Energy Production Technologies”.
Mail: babayeva_sevinc64@mail.ru

Shikhkarimov Nazim Nizami - In 2009 he entered the Azerbaijan State Oil and Industry University (former Azerbaijan State Oil Academy), Faculty of Energy, specialty "Thermal Power Engineering". After graduating with a bachelor's degree, in 2016, he received a master's degree in "Industrial Thermal Power Engineering" from the same faculty. He currently works as a lecturer and leading engineer at the Azerbaijan State Oil and Industry University. Since 2019, he has been conducting research at the doctoral level (Ph.D.) of the "Industrial Thermal Power Engineering" department of the "Energy Production Technologies" department of the Azerbaijan State Oil and Industry University. Research areas: "Renewable energy resources, energy sustainability, biogas technologies, the role of agriculture in the energy sector, bioenergy”.
Mail: nazim.shixkerimov@gmail.com

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SİSTEM QƏZALARININ İNKİŞAF MEXANİZMİNİN ANALİZİ VƏ ONLARIN ELEKTROENERGETİKA SİSTEMİNİN DAYANIQLIĞINA TƏSİRİ

ƏLİYEV A.Q

İşdə elektroenergetika sistemində yaranan sistem qəzalarının analizi və onların generatorların paralel işinin dayanıqlığına təsiri məsələlərinə baxılmış və müxtəlif tipli həyəcanlanmalar zamanı generatorların rotorları arasındakı bucağın rəqs etməsi araşdırılmışdır. Sistemin dinamik dayanıqlığına təsir edən əsas faktorlar müəyyən edilmişdir. MatLab PSAT proqram paketindən istifadə etməklə qəbul olunmuş test sxemi əsasında qəzanın inkişafının başlanğıc mərhələsində generatorların daxili bucaqlarının hərəkətinin, stator cərəyanlarının və gərginliklərin zaman diaqramları qurulmuşdur.

Açar sözlər: Elektroenergetika sistemi, dinamik dayanıqlıq, sinxron generator, təsirlənmənin avtomatik tənzimlənməsi, sistem qəzası, qısa-qapanma

АНАЛИЗ МЕХАНИЗМА РАЗВИТИЯ СИСТЕМНЫХ АВАРИИ И ИХ ВЛИЯНИЕ НА УСТОЙЧИВОСТ ЭЛЕКТРОЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ

АЛИЕВ А. Г

В работе рассмотрены вопросы анализа системных аварии в энергосистеме и их влияние на устойчивость параллельной работы генераторов, а также исследованы колебания угла между роторами генераторов при различных типах возбуждения. Выявлены основные факторы, влияющие на динамическую устойчивость системы. На основе общепринятой тестевой схемы испытаний с помощью программного комплекса MatLab PSAT, на начальном этапе развития аварии были построены временные диаграммы внутренних углов, токов и напряжение статора генераторов.

Ключевые слова: Электроэнергетическая система, динамическая устойчивость, автоматическое регулирование возбуждение, системная авария, короткое замыкания

ANALYSIS OF THE DEVELOPMENT PROCESS OF SYSTEM ACCIDENTS AND THEIR IMPACT ON THE STABILITY OF THE ELECTRIC POWER SYSTEM

ALİYEV A. G

The analysis of system accidents in the power system and their effect on the stability of parallel operation of generators has been considered. Oscillation of the angle between the rotors of generators during different types of excitation has been also investigated. The main factors violating the dynamic stability of the system have been identified. Based on the test scheme adopted using the MatLab PSAT software package, time diagrams of the movement of the internal angles of the generators, stator currents and voltages at the initial stage of the accident development were constructed.

Key words: Power system, transient stability, synchronous generator, automatic adjustment of the exposure, system crash, short circuit

Introduction. System failures in the power systems of many countries (USA, Canada, the European Union, India, Russia, Azerbaijan, etc.) have significant impact on the social and economic life of these countries. The main reasons for such accidents are increasing electricity demand, subsequent construction of new power grids and systems as well as structural variability in the power sector. As for the technical causes of these incidents, it is necessary to notice the fact that most of such accidents occur in power systems with complex structures. It means that the main limiting factors in power system are the stability limitations by current and voltage. Besides, the regularity of the development of large system accidents shows that all these accidents occur on the base of the same scenario. After the first serious failure next failure occurs causing black out in the large part of the power system. After the initial disturbance power system behaves as a system of relatively normal voltage and frequency for some time followed by overload and cascading tripping of the line as well as a deep voltage breakdown lasting several seconds. The first serious disturbance causes increase in reactive power loss in the system and increase in reactive power produced by synchronous machines near the location of damage. The initial disturbance occurs as a local problem and after some time subsystem and power system stop working due to the lack of reactive power in the damaged subsystem caused by the tripping of the overloaded generator [2,3].

Transient processes in the basic power elements of the system such as synchronous generators, mechanical and electrical transmission systems, etc. are one of the main factors determining the rational design of the power system (PS) and the violation of dynamic stability during its operation. It should be noted that the issue of increasing the dynamic stability which is violated due to the ongoing transient processes remains a research issue due to the complexity of adequately describing the physical processes that take place in the main power elements under emergency conditions.

1. Analysis of the process of system accidents development and their relationship with the stability of the power system

The analysis of the regularity of the development of system accidents allows to select the basic stages such as the pre-accident situation, causes of accident, steady state situation and recovery.

Pre-accident condition of the system is characterized by several factors:

1. Deterioration of equipment;
2. Deficit of reactive power in the system;
3. Seasonal load changes;
4. Severe climate and weather conditions;
5. The human factor.

It"s obvious that equipment deterioration and deficit of reactive power are subjective reasons which should be handled by the operating organization. Significant pre-accident overloading of the system may be caused by improper management of the present mode by the dispatcher due to the imperfection of the normative and technical guides. Disturbances (short-circuit, overload, failure of relay protection, loss of exposure, etc.) either directly cause the accident or lead to deterioration of the present mode.

The study of system accidents that occurred between 1965 and 2018 shows that the most common types of accidents are mainly voltage breakdowns as well as the equipment overloads. (Table 1)

Different types of Accidents

S.S	System accident, date, country	Types of Accidents			
		Voltage breakdown	Frequencyb reakdown	Equipments overload	Loss of Synchronism
1	9.11.1965, USA	-	-	+	-
2	31.07.1975, Kazakhstan	-	+	-	+
3	13.07.1977, New York, USA	-	+	-	-
4	19.12.1978, France	+	-	+	-
5	2.07.1996, USA	+	-	+	-
6	07.08.1996, USA	+	-	+	-
7	14.08.2003, North-East of USA and Canada	+	-	+	-
8	23.09.2003, East of Danmark and South of Sweden	+	-	+	-
10	28.09.2003, Italy	-	+	+	+
11	12.07.2004, Aehens and South of Greece	+	-	_	
12	14.03.2005, South of Australia	-	-	-	+
13	25.05.2005, Moscow, Russia	+	-	+	-
14	31.07.2012, India	+	-	+	-
15	03.07.2018, Azerbaijan	+	-	+	-

It should be noted that the problem of system stability is a matter of great importance during the design and operation of the power system.

The limitations of the stability of the power system can be divided into two types:

1. Stability by voltage (voltage stability in the load nodes of the system);
2. Stability of parallel operation of generators.

Stability by voltage depends on the value and distribution of reactive power. It is advisable to consider dynamic and static stability during its study.

Dynamic stability by voltage includes a comprehensive study of dynamic properties of electric motors, different types of loads, regulation of transformers under the load during the transient process.

Static stability by voltage is considered on the base of the analysis of the operation of loads during the smooth change of mode parameters.

The analysis of the stability of the parallel operation of generators deals with the oscillation of the angle between the rotors of the generators during different types of disturbances in the power system. Figure 1 shows the limits of the transmitted power (P) depending on the length of the overhead transmission line (L) as well as the characteristics illustrating the relationship between them and different types of stability.

Voltage and current boundary values are considered as a basic factors in the study of the stability of a complex multi-circuit power system including medium-length lines (large industrial centers, megacities grids). The main factor affecting the system stability by voltage is the value of reactive power.

The main factor limiting the study of long-distance and large-scale power systems and intersystem communicationы is the stability of parallel operation of generators. The location and type of damage are factors that affect the stability of the parallel operation of generators. Thus, it should be mentioned that all these limitations as well as the type of stability often depend on the structure of the power system.

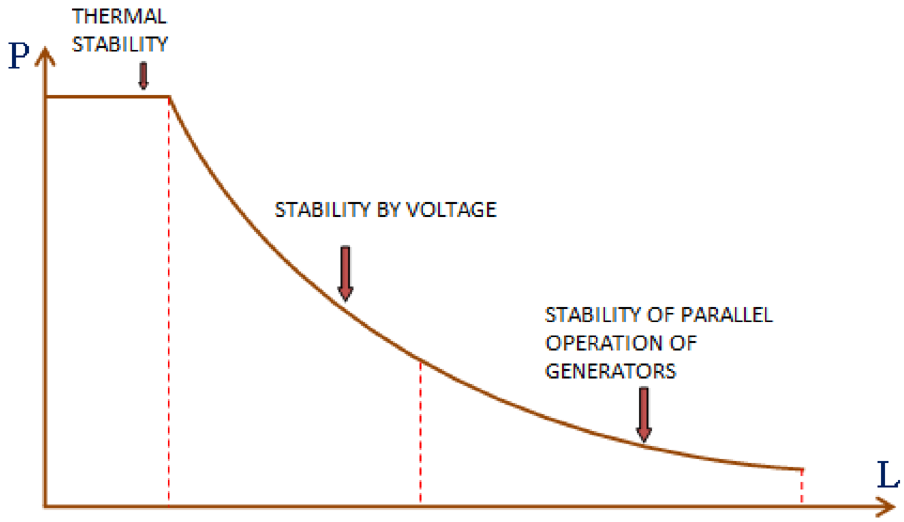


Fig.1. Boundary characteristic of the transmitted power depending on the length of the line.

One of the main tools used to maintain the parallel operation of power stations is called Automation System for Maintaining of Stability (ASMS).

Thus, it can be concluded that when discussing of stability in huge energy regions with high concentrations of generation plants and consumers, it is necessary to pay attention at overloads of grid elements, as well as control of reactive power and voltage values.

In some European countries voltage and reactive power control is based on the principle of dividing the power system into controlled zones. The division of the power system into such zones is called the concentration of generation nodes [5,6].

Table 1 shows that most system failures in different countries occurred at nominal frequency. At the same time research shows that accidents in those countries occurred on the basis of the same scenario. Just after the first disturbance several accidents occur causing the tripping of a very large part of the system. After the first disturbance voltage and frequency keep their normal values for some time. Then the transmission lines are tripped causing voltage breakdown for a few seconds. The first serious disturbance leads to an increase in reactive power loss in the system and an increase in reactive power production by synchronous machines near the site of accident. It means that first disturbance is a local problem. Over some time the deficit of reactive power in a damaged system can increase significantly. For example, tripping of loaded generator can lead to the collapse of a nearby subsystem or the system as a whole.

2. Analysis of the initial stage of the system accident for single-line test scheme consisting of 10 nodes of the power system

In order to analyze the accident in the power system MatLab PSAT software is used.

The test scheme shown in Figure 2 was studied under the following conditions:

1. G1 and G2 generators are equipped with turbine speed regulator (TSR) and automatic excitation control system (AECS). G1 generator is considered as an infinite power source;

2. The G3 generator is equipped with the field current limiter. The relative limit value of the field current is 12 r.u;
3. The transformer in branches 9-10 is equipped with an automatic regulator of the transformation coefficient under the load.

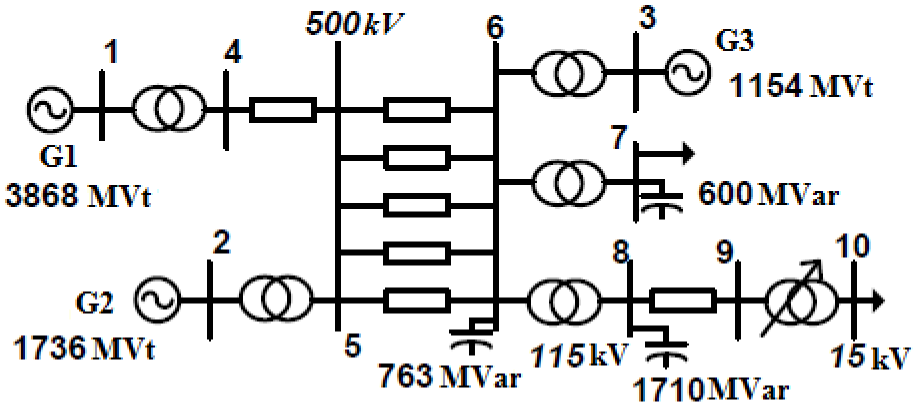


Fig.2. Test model of power system

Thus, accidents are carried out in the following sequence:
1. As a result of a three-phase short-circuit near node 5 in 2 seconds one of the lines connecting 5-6 nodes is tripped. Transient impedance at short-circuit is 0.01 Ohm. There is no automatic reconnection (ARC) on the transmission line. Duration of short-circuit is 0.12 seconds;
2. At 30 second a static capacitor battery with a capacity of 600 MVar is tripped at the 7th node.

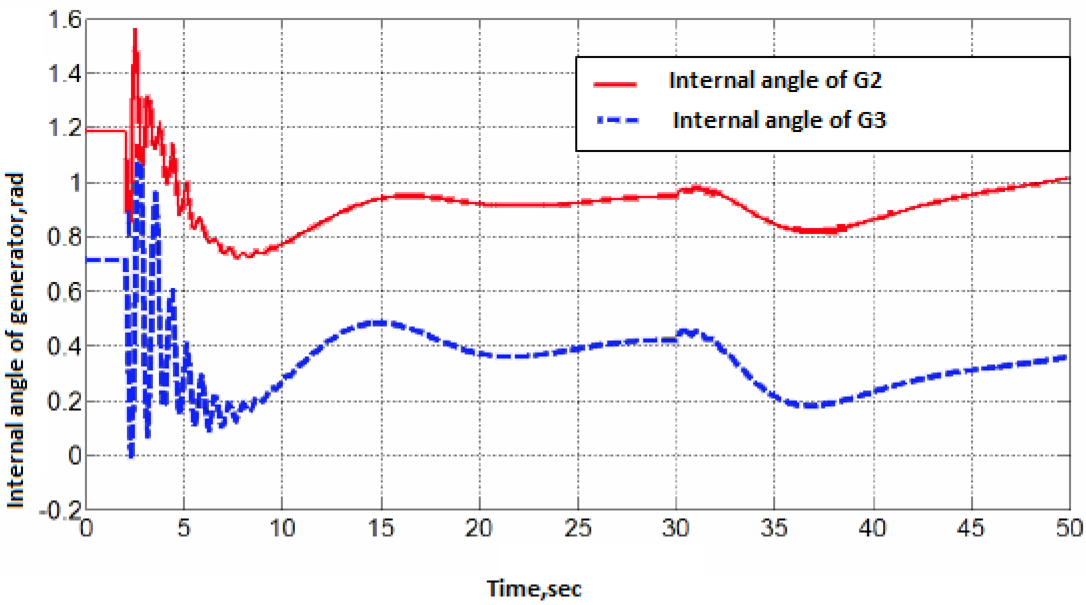


Fig 3. Time diagram of the motion of the internal angles of G2 and G3 generators at the initial stage of the accident

As it seen from Fig.3 tripping of 5-6 lines during a three-phase short circuit near 5 node in 2 seconds does not cause violation of the stability of the system under consideration. In this case the rotors of the G2 and G3 generators rotate practically synchronously. This is clear from the time diagram in Figure 3. Thus, the stability of the parallel operation of the generators is not the main determining factor for the test circuit. The reason is their close location

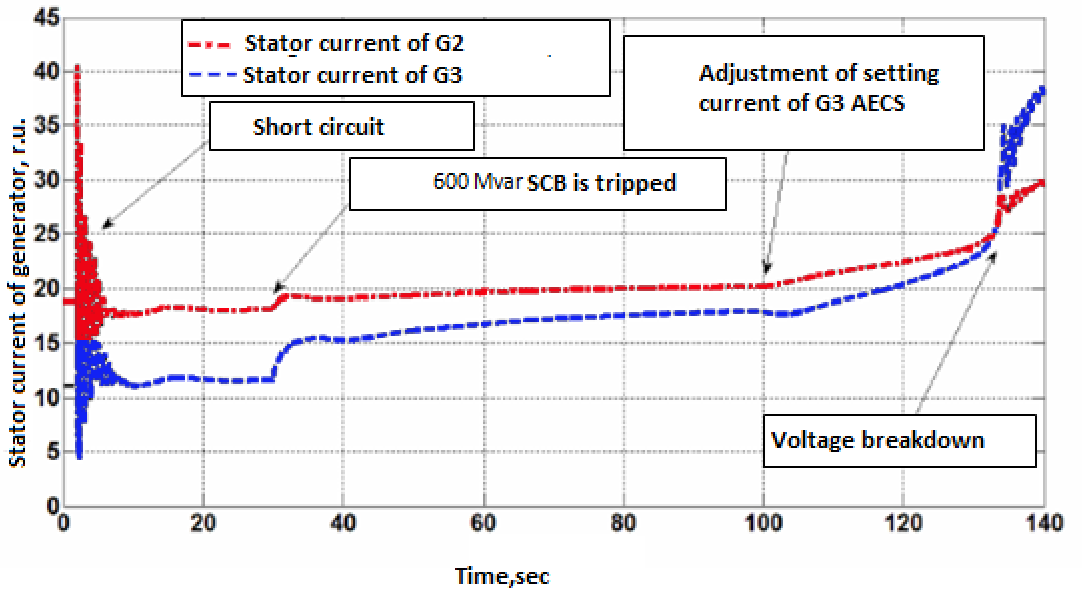


Fig.4. Stator currents of G2 and G3 generators during accident development.

As it seen from Fig. 4, there is a deficit of reactive power in the system due to the tripping of the SCB with a capacity of 600 MVar at node 7 in 30 seconds. In this case the main load is taken by G3 generator. The additional load of this generator due to the reactive power is caused by increase of its stator current. After some time passing by the stator and rotor currents of G3 generator reach the limit value as a result of the automatic adjustment of the transformation coefficient of the transformer in the node 10. Stator current increase can also be caused by a natural increase in load during the day. This leads to the development of the accident. In this case current load of G3 generator should be reduced. According to the rules technical stuff do not have the right to reduce the active load of the generator without the order of the dispatcher. However, one should try to reduce the reactive power load of the generator by means of AECS setting current adjustment. In this case as shown in Fig.5 reduction of reactive power supply when the applied AECS current is reduced from 1.04 to 1 in relative units increases the reactive power demand by the load and the field current reduction device in the system causes the deep voltage breakdown (Fig. 6).

A drop in voltage leads to a steady increase in the stator current of the G2 and G3 generators which causes them to be quickly tripped by the relay protection. This stimulates the process of cascade tripping of the transmission lines of the nearby subsystem.

It is known that short-term forcing of the generator excitement provides efficient voltage recovery. However, short-term forcing of excitement is used to improve the quality of the transient process only in the case of large disturbances. Therefore, deep voltage breakdown is caused by long-term stator and rotor currents increase. As a result, relay protection trips overloaded generators. For this reason forcing of overloaded generator excitement cannot be used as efficient method to prevent further accident development.

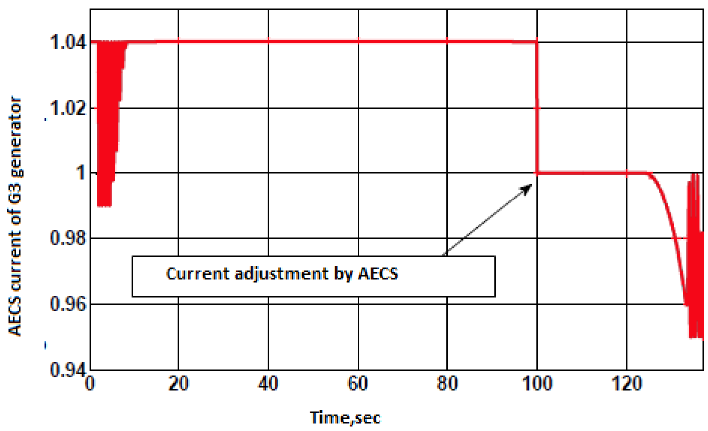


Fig.5. Correction of AECS current of G3 generator during accident development

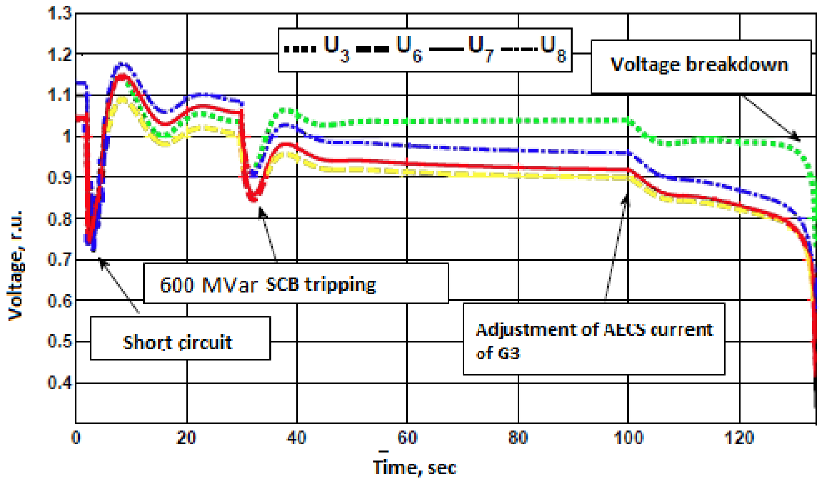


Fig.6. Time diagram of the busbar voltages during the accident development.

SUMMARY

As a result of analysis of power system accidents development and study of its impact on the stability of the power system, it was determined that:

1. Overloading of grid elements as well as the values of reactive power and voltage are the main factors violating stability in the huge energy regions with high concentrations of generation units and consumers;
2. Measures taken to prevent the cascade development of accidents may not be effective;
3. Automatic adjustment of the transformation coefficient creates conditions for aggravation of the situation;
4. In a power system of complex structure with medium-length transmission lines (large industrial centers, megacities grids) violation of stability by voltage can lead to system accidents.

BIBLIOGRAPHY

1. Коган Ф.Л. О причинах развития известной аварии в Московской энергосистеме//Электричество.-2008.-№5.-с.69-72.
2. Lachs W.R. Controlling grid integrity after power system emergencies // IEEE Transactions on Power Systems. _ 2002. _ May. _ Vol. 17, No. 2. _ Pp. 445_450.
3. Lachs W.R., Sutanto D. Voltage instability in interconnected power systems: a simulation approach // IEEE Transactions on Power Systems. _ 1992. _ May. _ Vol. 7, No. 2. _ Pp. 753_761.
4. Коган Ф.Л., РубашкинА.С., ПойдоА.И. идр. Применение компьютерной модели для анализа аварийных ситуации в энергосистеме // Электрические стации.-2009.-№1.-с.36-44.
5. C. Vournas, Lambrou C., M. Glavic, T. Vancutsem. An integrated autonomous protection system against voltage instability based on Load Tap Changers // 2010 IREP Symposium Bulk Power System Dynamics and Control - VIII (IREP). _ IEEE, 2010. _ Aug.
6. Горожанкин П.А., Майоров А.В., Макаровский С.Н., Рубцов А.А. Управление напряжением и реактивной мощностью в электроэнергетических системах. Европейскийопыт.// Электрическиестанции.-2008.-№6.-с.40-47.
7. Milano F. An open source power system analysis toolbox // 2006 IEEE Power Engineering Society General Meeting. _ IEEE, 2006.
8. Герасимов А.С., Есипович А.Х., Кощеев Л.А., Шульгинов Н.Г. Исследования режимов Московской Энергосистемы в процессе развития аварии в мае 2005 г//Электричество.-2008.-№1.

Floating solar system and application

Mammadov R.R.
Azərbaijan Renewable Energy Agency
Head of Monitoring and Data Analysis Department of
"Azalternativenerji" LLC
Mobile: +994502916441, e-mail: rsm_mamedov@hotmail.com

Floating Solar Station and Application

Annotation:The article provides an analysis of the floating solar power market, the current situation in the world, investment capacity, measurements, use of existing solar radiation and other issues. Information was provided on solar radiation in Lake Boyukshor and the potential energy production from it. Information was provided on the structure of the 95 kW floating solar station and electricity generation.

Keywords: floating solar station, solar energy, water, lake, photovoltaic panels, pantone

Annatasiya: Məqalədə üzən günəş stansiyalırı bazarının təhlili, dünyada bu günki vəziyyət, qoyuluş gücü, ölçmələr, mövcud günəş radiasiyasından yararlanmaq kimi məsələlər qoyulmuşdur. Böyükşor göləndə günəş radiasiyası və bundan alınması ehtimal olunan enerji istehsalı barədə məlumat verilmiş. 95 kVt gücündə üzən günəş stansiyasının həm sturkturu barədə məlumat verilmiş və elektrik istehsalı göstərilmişdir.

Açar sözlər: üzən günəş stansiyası, günəş enerjisi, su, göl, fotovoltaik panellər, panton.

В статье представлен анализ рынка плавающего солнечной энергии, текущая ситуация в мире, инвестиционный потенциал, измерения, использование существующей солнечной радиации и другие вопросы. Была предоставлена информация о солнечной радиации в озере Беюкшор и потенциальном производстве энергии из нее. Была предоставлена информация о структуре плавучей солнечной станции мощностью 95 кВт и производстве электроэнергии.

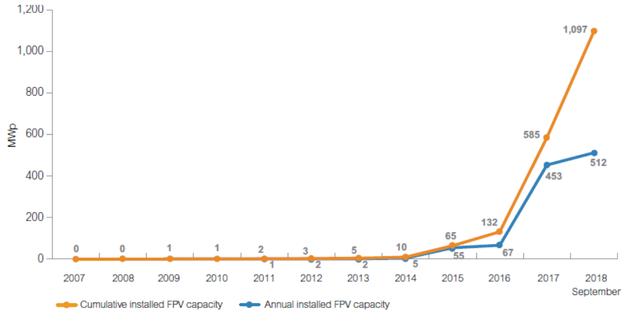
Ключевые слова: плавучая солнечная станция, солнечная энергия, вода, озеро, фотоэлектрические панели, понтоны.

Introduction

Today, the application of alternative and renewable energy covers a wider area in the world. Of course, it is possible to apply different fields depending on the type of potential in the area. Solar, wind, biogas, briquette production, waste and more includes here. As we know, the sun is a more widely used source of energy. Because the sun is almost everywhere. In some cases, long-distance transmission lines are either expensive or impossible due to the difficult terrain. In the field of application of solar energy, the world today has witnessed successful development in five directions, including ground-mounted, roof-top, canal-top, offshore and floating. One of them is the construction and application of "floating solar energy systems". The integration of renewable energy and water sources can play an important role in the development of the agricultural and tourism sectors especially in terms of development of remote areas.

According to the first market report on floating solar, prepared by the World Bank Group and the Singapore Solar Energy Research Institute (SERIS), the use of floating solar - the placement of photovoltaic panels on the surface of water bodies - in less than four years, from 10MW installed in late 2014 to 2018 increased more than a hundred times to 1.1GW by September (Figure 1). In some large hydropower plants, covering only 3-4 percent of the reservoir with floating solar can double the plant's capacity and allow for more strategic management of water resources using solar energy during the day.

FIGURE 1 Global installed floating PV capacity



Source: Authors' compilation based on media releases and industry information.

It can also be used to combine solar and hydropower to correct the variability of solar energy. Although the initial costs are somewhat higher, the costs of the floating solar due to the higher energy production of the floating solar due to the cooling effect of the water are approximately the same as the traditional solar installed on the ground.

Research shows that with hundreds of megawatts of large floating solar stations installed or planned in China, India and Southeast Asia, Asia could be the center of this new technology expansion. Demand for this technology is expected to increase and the floating solar is expected to be a bigger part of the countries' plans to expand renewable energy. It is important to ensure that best practices are shared between countries and that development minimizes environmental impacts. NREL has released a study claiming that if solar panels are installed in only a quarter of man-made water bodies in the United States in 2018, it will account for 10% of the country's electricity needs.

Swimsol was founded in 2012 by Martin Putschek. Two years later, in collaboration with theVienna University of Technology and the Fraunhofer Institute in Germany, they launched the world's first floating solar power plant for the marine environment - SolarSea. The highest capacity and energy production potential of FPV in freshwater reservoirs across the continent.(Table 1)

TABLE 1. Peak capacity and energy generation potential of floating solar on freshwater man-made reservoirs, by continent

Continent	Total surface area available (km^2)	Number of water bodies assessed	Floating PV potential (GWp) Percentage of total surface area used			Possible annual energy generation (GWh/year) Percentage of total surface area used		
			1%	5%	10%	1%	5%	10%
Africa	101,130	724	101	506	1,011	167,165	835,824	1,671,648
Middle East and Asia	115,621	2,041	116	578	1,156	128,691	643,456	1,286,911
Europe	20,424	1,082	20	102	204	19,574	97,868	195,736
North America	126,017	2,248	126	630	1,260	140,815	704,076	1,408,153
Australia and Oceania	4,991	254	5	25	50	6,713	33,565	67,131
South America	36,271	299	36	181	363	58,151	290,753	581,507
Total	**404,454**	**6,648**	**404**	**2,022**	**4,044**	**521,109**	**2,605,542**	**5,211,086**

Source: SERIS calculations based on the Global Solar Atlas and Lehner et al. (2011a, 2011b).
Note: GWh = gigawatt-hour; GWp = gigawatt-peak; km^2 = square kilometers; PV = photovoltaic.

The Advantages and Disadvantages of Floating Solar Panels. Floating solar panels, also known as floating photovoltaic (FPV), are any kind of solar panels that float on water. Solar panels need to affix to a structure that will keep them above the surface. Floating solar panel installations will be located on the lakes, large man-made bodies of water, such as reservoirs and so on. Floating solar panels are a relatively new concept. The first patent for this type of solar technology was registered in 2008.

The Advantages of Floating Solar Panels. There are some major environmental benefits when it comes to solar energy, and floating solar panels certainly will play a role in contributing to the environmental benefits of solar energy. The floating solar panel installation provides shade to the body of water and reduces the evaporation from these ponds, reservoirs, and the lakes. This is a particularly useful environmental benefit of solar energy in areas that are more susceptible to droughts, as water loss due to evaporation and can add up over time and contribute to a shortage. The shade that the floating solar panels produce can help reduce the presence of algae that blooms in the freshwater. The algae can be a little dangerous for human health if they occur in a source of the drinking water, and it can also lead to the death of plants and animals that live in the water. The floating solar systems are a clean source of renewable energy. The use of sources of renewable energy technologies helps decrease the emission of greenhouse gas emissions and all of the other pollutants that they put in the atmosphere, leaving a positive impact on the environment as well as human health. For example the potential of floating PV systems can reach 160 GW in China, covering about 2500 km^2 water surface. This would help to save 2*1027 m^3 water from evaporation a year. If the saved water can be used by hydropower, it would further contribute about 1.25*1012 m^3 of indirect water saving.

No Loss of Valuable Land Space. One of the biggest advantages of floating solar panels is the solar panel installations don't require any land space. Most of these solar panel installations can take unused space on bodies of water, such as hydroelectric dam reservoirs, wastewater treatment ponds, or drinking water reservoirs. In addition, during of the installation of the larger solar stations reduces the tree removal and forest clearing. Major site preparation, such as leveling or the laying of foundations, which must be done for land-based installations are eliminate.

Easy installation and deployment in sites with low anchoring and mooring requirements.

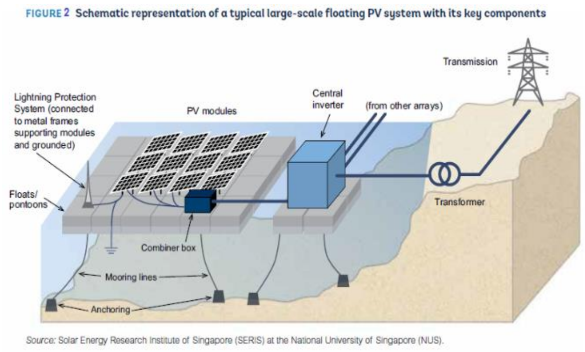
Increased Efficiency of a Solar Panel. Solar Panels are durable and can perform under high temperatures. But same as other electronics, with higher temperatures, come with decreased power outputs. The efficiency of a solar panel tends to decrease as the temperatures rise, which can be concerning for property owners who are looking to get a solar panel installation in a hot and sunny climate. Water, will help the solar-powered systems cool down and will increase the efficiency of the solar panels, especially in the hot climate regions. Addition, with floating solar panel installations, the water doesn't only have a cooling effect on the solar-powered systems, it works the other way as well. The reduction of dust can have a positive effect on the energy production and reduce service costs.

Cons of Floating Solar Panels. A floating solar panel installation might require additional costs than more traditional solar panel installations. Because this is a relatively new solar power technology it requires specialized solar power equipment and more niche solar panel installation knowledge, it will typically require a higher price tag than installing a similar-sized solar power farm on a rooftop, or solid ground. But just like with more traditional solar-powered systems, the costs of getting a floating solar panel installation are expecting to drop as the technology advances.

Fishing and transportation activities may be affected by the floating system. Of course we can develop aquaculture in the same water too.

Located within the water environment could lead to the corrosion of modules and structures, thus could reduce the system lifetime. These effects should be taken into account when choosing equipment.

An overview of floating solar technology. The general layout of a floating PV system is similar to that of a land-based PV system.(Figure 2).



A floating solar PV system consists of four components that are the floating system, mooring system, on the water or underwater cables and the PV system.

(1). Floating System: A floating body, including structure and floater, that allows the installation of the PV module.

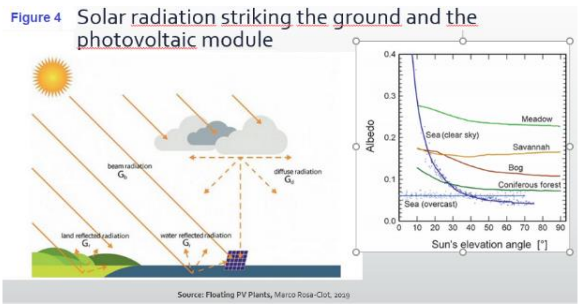
(2). Mooring System: Can adjust to water level fluctuations while maintaining its position in a southward direction.

(3). On the water or underwater cable: Transfers the generated power from FPV system to the substation.

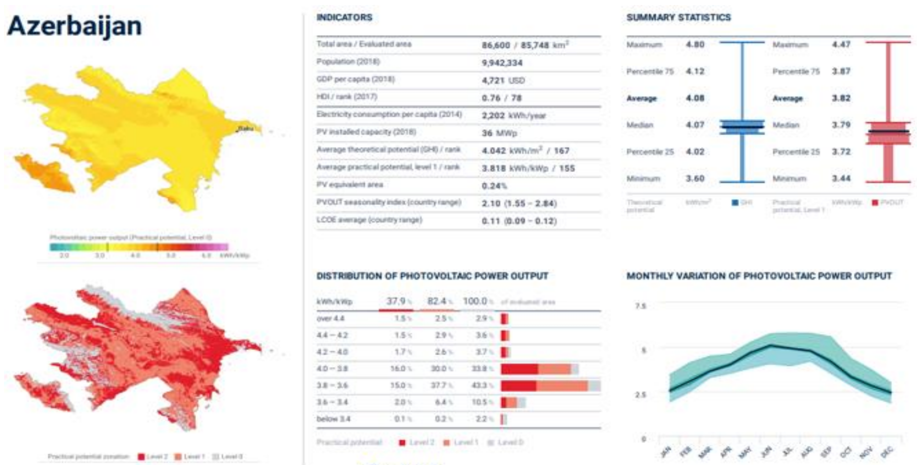
(4). PV System: Energy generation equipments, that are PV modules installed on top of the floating system, inverter, controller, substation and distribution line.

The direct current (DC) electricity generated by PV modules is gathered by combiner boxes and converted to alternating current (AC) by inverters. For small-scale floating plants close to shore, it is possible to place the inverters on land— that is, just a short distance from the array. Otherwise, both central or string inverters on specially designed floats are typically used. On the picture below for a visual representation. The picture below also shows a 400 MW floating solar station and a simplified installation method. The suitability of the floating solar station for significant changes in water levels has also been shown. (Figure 3)

Solar energy potensial in Azerbaijan. Of course, when talking about the development of solar energy or its application to any field, the potential in the area must be studied first. The next picture also shows the solar radiation on the ground and on the PV panel.(Figure 4). Here we are talking about direct, diffuse and global radiation. Azerbaijan's solar potential is not too high and not too low. This figure varies between 1200 kW * h / m^2 / year -1800kW * h / m^2 / year. These figures can also be seen in the graphs below. Azerbaijan is among the countries with medium solar potential.

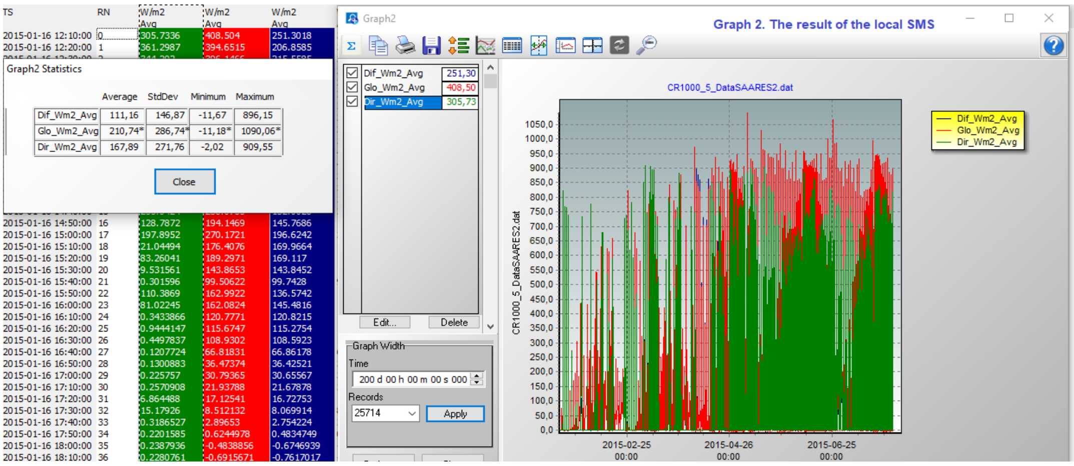


(Graph 1. Global Solar Atlast)

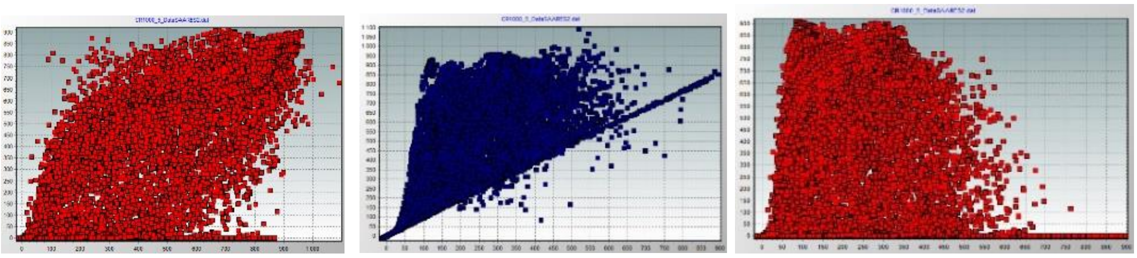


Graph 1

Solar monitoring station data. Solar Monitoring Station(SMS) installed in the yard of Suraxanı Solar Energy Station. It is located not far from Boyukshor lake. We can apply to the SMS data in Baku region. Characteristics of average solar radiation during the months 16.01.2015-30.7.2015. This chart is based on 200 days of data. As can be seen, the solar radiation in the area is high, according to the results obtained from local observation stations. For information, the station records data every ten minutes by tracking the sun during the day.(Graph 2)



XY plots (Graph 3)



Graph 3

Lakes of the republic of Azerbaijan. Azerbaijan is located at the foot of the Caucasus Mountains, in the southern Caucasus. There are many natural lakes and reservoirs in the country. 61 lakes with at least 100 hectares in Azerbaijan have been listed for a useful PV network. Several others were identified and inspected, but the target was less than 100 hectares. More than 50% of the total water area is not intended for development . After analysis, the number of lakes was reduced to 42.

List of the lakes and reservoirs in Azerbaijan.(Table 2)

Id	Name	Area(ha)	Type
1	Mingechevir Reservoir	47351	hydro
2	Semkir Reservoir	7816	hydro
3	Near Lənkaran (location)	5978	

4	South of Elvend (location)	4866	
5	Aras Govsaghynyn Reservoir	4701	hydro
6	Yenikend Reservoir	2267	hydro
7	Jeyranbatan Reservoir	1268	
8	Khoda Afarin Reservoir	1101	hydro
9	Lake Massazyrgol	956	
10	Lake Massazyrgol	934	
11	Sarsang Reservoir	893	hydro
12	Varvara Reservoir	884	hydro
13	Near Tazakand (location)	653	
14	Mehmangyol	608	
15	Mets Al Lakea	511	
16	Jandara Reservoir	489	
17	Boyukshor lake 2	448	
18	Hajiqabul Lake	410	
19	Lake Mirzaladi	388	
20	Agstafachay reservoir	375	
21	Arpachay Reservoirs	352	

Table 2

List of the lakes and reservoirs in Azerbaijan.(Table 3)

Id	Name	Area (ha)	Type
22	Arpachay Reservoirs	352	-
23	Boyukshor lake 1	256	-

24	Pirsaat	248	
25	Vilash Reservoir	238	-
26	Near Bilasuvar (location)	222	-
27	Lake Ag-Gol 1	213	-
28	Boyukshor lake 3	193	-
29	South of Mingechevir (location)	192	hydro
30	Ayricay Su Anbari reservoir	173	-
31	Yekakhana Reservoir	163	-
32	Lake near Kurdexani (location)	159	-
33	Xaçin Su Anbari	156	-
34	Khojahasan lake	155	
35	Near Bileh Savar (location)	139	-
36	Nohur Lake	131	-
37	Qumyataq Golu Lake	120	-
38	mil-Mughan Water Reservoir	116	hydro
39	Lovain Reservoir	114	-
40	Khanbulan Reservoir	112	-
41	UzunOba	101	
42	Zigh Lake	100	-

Table 3

The largest potential areas / forces are indicated by the following lakes, but some may not be suitable for use or full development:

- Khudaferin: 583 MW, source of drinking water
- Jeyranbatan: 702 MW, allocated for water supply
- Masazırgölü Lake: 656 MW, slightly polluted, but less than others
- Boyukshor Lake 2: 303 MW, but very polluted
- Lower-Cross Lake: 345 MW, but used for fishing due to living may affect capabilities

Of course, these data are approximate figures and will be clarified when each lake is surveyed separately.

List of the substations in Azerbaijan. List of substations per each lake was obtained from the Azerenergi grid map. For the lakes outside of the Absheron peninsula the distances between the lakes and the identified substations was gathered (within the errors of the GIS data). For the lakes in the Absheron peninsula the same was done, but only for the furthest and the closest substation (due to the significant number of substations identified). An analysis was done regarding the potential size of deployment in the selected lakes and the feasible capacity based on not more than 50% of the area of the lake (considering 1,25 ha per MWac) and the estimated capacity of the transmission lines identified in the premises of the substations (it was considered for single lines 100 MW for 110 kV, 150 MW for 154 kV and 200 MW for 220-230 kV). A total of almost 4 GW is possible with a total of around 1.3 GW being feasible.

List of the substations in Azerbaijan. (Table 4)

#	Name of the lake	Line voltage level (kV)	Line capacity (MW)	Area required (ha)	Total area available (ha)	Feasible area (ha)	Potential MW	Feasible MW	Substation	Distance to substation (km)	Usage / comments
	Existing substations										
1	Ayricay Su Anbari	110	100	125	173	127	101,6	69,2	Şəki	7,1	
2	Nohur	110	100	125	131	108	86,4	52,4	Qəbələ	2,4	
		220-230	200	250	131	108	86,4	52,4	Qəbələ	2,4	
3	Xaçin	110	100	125	156	124	99,2	62,4	Sırxavənd	5,1	Fisheries
		110	100	125	156	124	99,2	62,4	Mollakənd	4,3	
4	Mil Mughan	110	100	125	116	87	69,6	46,4	Şükürbəyli	5	Source of drinking water
5	Khoda Afarin	110	100	125	1101	729	583,2	100	Xudafərin	4,5	Source of drinking water
6	Jeyranbatan	110	100	125	1268	878	702,4	100	Yasamal 2	9,7	Water supply
		110	100	125	1268	878	702,4	100	Həsənoğlu LTD	< 1	
7	Lake Massazyrgol	110	100	125	956	820	656,0	100	Sənaye Qovşağı	9,6	Oil products, 0.04 mg/l
		220-230	200	250	956	820	656,0	200	Sənaye Qovşağı	9,6	
		110	100	125	956	820	656,0	100	83	< 1	
8	Lake Qumyataq	110	100	125	120	102	81,6	48	Xirdalan	8,3	Bird watching

Table 4

List of the substations in Azerbaijan. (Table5)

#	Name of the lake	Line voltage level (kV)	Line capacity (MW)	Area required (ha)	Total area available (ha)	Feasible area (ha)	Potential MW	Feasible MW	Substation	Distance to substation (km)	Usage / comments
	Golu	220-230	200	250	120	102	81,6	48	Xirdalan	8,3	in the lake area
		110	100	125	120	102	81,6	48	Ceyranbatan	3,4	
		220-230	200	250	120	102	81,6	48	Ceyranbatan	3,4	
9	Lake Mirzaladi	110	100	125	388	305	244,0	100	MKZ	8,7	Dry area during the summer covered with salt. The bottom below the salt has silt several meters deep, black and with oil products, 0.09 mg/l.
		110	100	125	388	305	244,0	100	Betk	3,2	
10	Zigh Lake	110	100	125	100	80	64,0	40	8 Km	8,8	Maximum depth is 2.8 m, amount of bottom sediments is 5.5 million m3, thickness of bottom
		110	100	125	100	80	64,0	40	Zig	< 1	

Table 5

List of the substations in Azerbaijan. (Table 6)

#	Name of the lake	Line voltage level (kV)	Line capacity (MW)	Area required (ha)	Total area available (ha)	Feasible area (ha)	Potential MW	Feasible MW	Substation	Distance to substation (km)	Usage / comments
11	Boyukshor lake 1	110	100	125	256	188	150,4	100	83	9,5	Untreated part of the lake is heavily polluted (oil products, 0.93 mg/l)
		110	100	125	256	188	150,4	100	204	1,7	
12	Boyukshor lake 2	110	100	125	448	379	303,2	100	e. Vahid	9,3	Heavily polluted (oil products, 0.93 mg/l)
		110	100	125	448	379	303,2	100	Nizami	< 1	
		220-230	200	250	448	379	303,2	179,2	Nizami	< 1	
13	Boyukshor lake 3	110	100	125	193	170	136,0	77,2	Betk	9,9	
		110	100	125	193	170	136,0	77,2	Nizami		
		220-230	200	250	448	379	303,2	179,2	Nizami	< 1	
14	Lake near Kurdexani	110	100	125	159	115	92,0	63,6	Mastaga	8,9	Utility wastewater, and oil wastes (oil products, 0.37 mg/l)
		110	100	125	159	115	92,0	63,6	Kurdexan	3,5	
15	Khojahasan lake	110	100	125	155	131	104,8	62	83	9,4	Oil products, 0.26 mg/l
		110	100	125	155	131	104,8	62	Yasamal 2	1,8	

Table 6

List of the substations in Azerbaijan. (Table 7)

#	Name of the lake	Line voltage level (kV)	Line capacity (MW)	Area required (ha)	Total area available (ha)	Feasible area (ha)	Potential MW	Feasible MW	Substation	Distance to substation (km)	Usage / comments
	Golu	220-230	200	250	120	102	81,6	48	Xirdalan	8,3	in the lake area
		110	100	125	120	102	81,6	48	Ceyranbatan	3,4	
		220-230	200	250	120	102	81,6	48	Ceyranbatan	3,4	
9	Lake Mirzaladi	110	100	125	388	305	244,0	100	MKZ	8,7	Dry area during the summer covered with salt. The bottom below the salt has silt several meters deep, black and with oil products, 0.09 mg/l.
		110	100	125	388	305	244,0	100	Betk	3,2	
10	Zigh Lake	110	100	125	100	80	64,0	40	8 Km	8,8	Maximum depth is 2.8 m, amount of bottom sediments is 5.5 million m3, thickness of bottom
		110	100	125	100	80	64,0	40	Zig	< 1	

Table 7

solar stations will be implement in Boyuk Shor. Boyuk Shor is one of the largest lakes in Azerbaijan. Located on the Absheron Peninsula, on the territory of Binagadi, Sabuchi and Narimanov districts of Baku. The volume of water is 0.0275 km³. The origin is relict. Area - 16.2 km², volume - 27.5 million m³. Height above sea level - 12.6 meters. The water is salty. The maximum width of the lake is 2 km, the maximum depth is 2 m, the average depth is 1.3 m, and the length of the coastline is 12 km. Based on the results of the World Bank Group's Global Solar Atlas, the lake's solar energy potential, energy production reports and graphs have been prepared. The following figures and graphs shows the hourly, daily and annual solar radiation in Lake Boyukshor and energy production.(Figure 5)

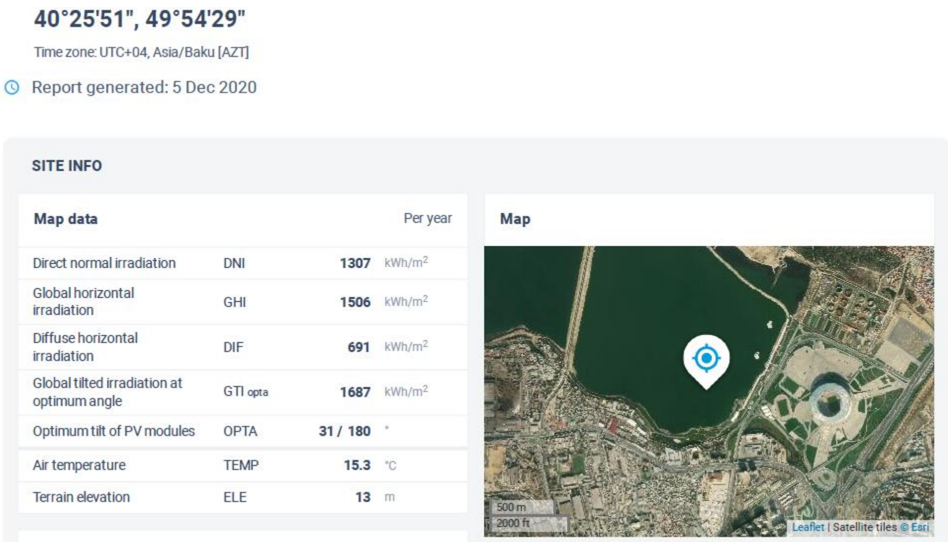
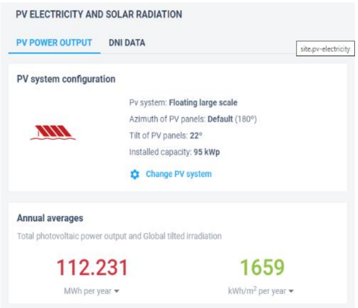
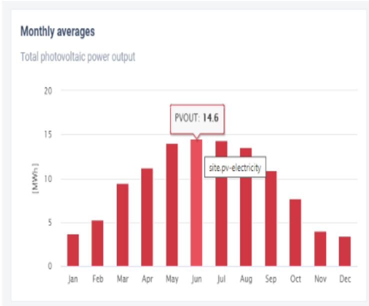


Figure 5.

In this graph below, we have tried to show the average annual solar radiation and the energy to be produced from the panels installed at an angle of 22^0 on the lake. Of course, we used NRG Island's floating solar system. According to the results of the PVSYST program, the annual energy production is approximately same. (Figure 6)





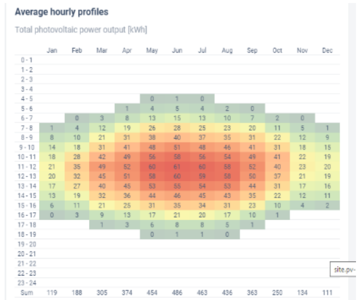


Figure 6 Graph 4 Graph 5

Technical parameters and energy production of 95kW floating solar station on Boyukshor lake. Of course, floating solar stations are designed in different type in the world today. The layout of a typical floating PV system is introduced in figure below. I will give a brief overview of floating solar systems manufactured by NRG Iceland.

Description and proposal for the supply of NRG Island floating structure to support a Photovoltaic System of 152 kWp with Trina TSM-DEG15M.20(II) 400 Wp PV panels of dimension 2.031 x 1.011 x 0.03 meters to be installed in Boyukshor lake, Azerbaijan.

Description of the NRG Icland system: The NRG Island system is modular and consist of UNITS that are horizontally and vertically replicable so that you can obtain the desired total power output.(Figure 7)

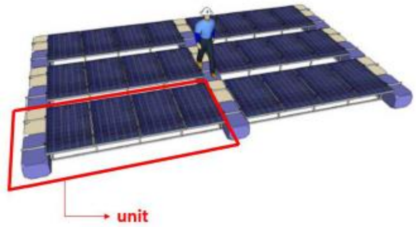
Figure 7 Floats made of HDPE

1 aluminum frame and 2 HDPE floats form a standard unit (Figure 8) of about 2 x 4,5 meters (in the case of 60-cell panels). With panels with 72 cells or more, another smaller HDPE float is required, as can be seen in (Figure 9), and units are bigger in size:

- if panels are narrower than 1,002 m, the unit is 2,5 x 4,5 m,
- if panels are wider than 1,002 m, the unit is 2,5 x 5 m.

1 "unit" 2x4.5m is composed with additional 50x50cm float by 2 floats + 1 frame (underlined in light blue) for 72 cells panels or more (plan view).

In our offer we provide ALUMINIUM FRAMES that can be anodized if needed. The system contains all the components needed to assemble the frames, connect the floats to one another, and the fasteners to secure the solar panels (standard panels with aluminium frames) to the frames



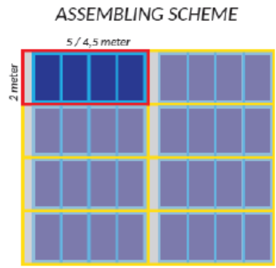


Figure 8. NRG System' plan and details: Figure 9. Example of NRG System

The floating structure of the Project: Data of the structure: Panels' tilt is 22°, Row pitch = 3 m, Panels are in portrait mode, Panels are South-oriented, Units are 2,5 x 5 m, PV - 288 unit.
Anchoring Scheme of a similar floating platform (it must replicate at least on 2 sides)

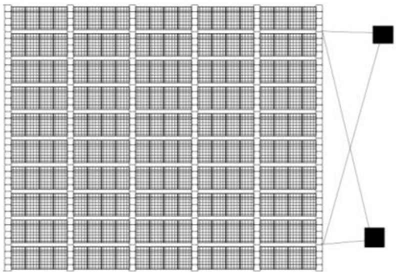


Figure 10. How to connect chains and dead weights

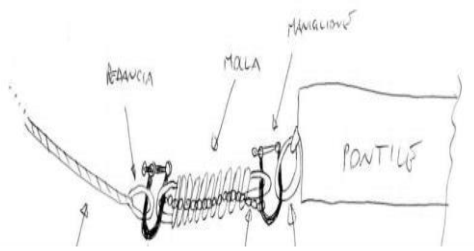


Figure 11. Steel spring

NRG Island patented system can withstand wind strength up to 250 km/h and our special anchoring system can adapt to any change in water level. Buoyancy capacity of floaters: 350kg/sqm.

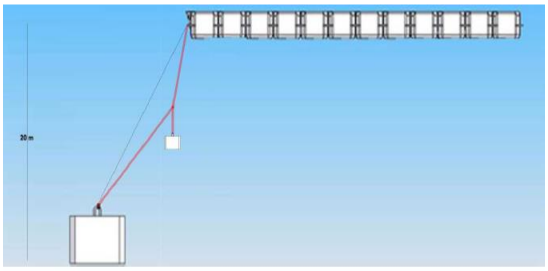


Figure 12. Cement weights and galvanized chains

Figure 12.

Water level's change: how to face it

The system is adaptable to variations in the water level, thanks to weights positioned at 1/3 of the chain length so as to always maintain tension in the system with regard to the level variations, as shown in the picture below. Is possible to anchor the plant to the shore or to the bottom of the reservoir.(Figure 12)

NRG Island advantages in brief:

• Any kind of panel with any tilt can be installed on it.

• The geometry design enables air circulation below modules preserving an adequate oxygenation of water. There are no floats beneath the panels.

• Bifacial panels can be installed to obtain an increase in solar power production. Our system enables the light that is reflected off the water surface to be captured by PV cells on the rear of the panels.

• The total area covered by PV panels is more than the 85 % of the total area of the plant.
• It's a modular system, easy and quick to install.
• Its compactness, stability and shape provide a steady walking surface for safe maintenance operations. Buoyancy capacity of floaters is 350 kg/mq.
• Floats can be of a blue or white-cream color. For large projects the color can be customized.

Moreover:
• The shielding effect on the water surface of the system reduces the water evaporation by up to 80% in a year (result of a pilot study conducted in Singapore by SERIS – Solar Energy Research Institute of Singapore and Figure 13 NUS University).

(Figure 13)

• Due to the mitigating effect of the water temperature on PV cells, the system shows an increased power production up to 15% compared to ground-mounted PV plants (result of a pilot study in Singapore by SERIS).

When the pilot project is installed, it is planned to build an observation station to measure the solar potential and other climatic data in the area.(Figure 14) Thus, the station will measure solar radiation, wind speed, wind direction, humidity, water and air temperature. Solar monitoring stations are automated data-acquisition systems specifically designed for the solar-energy industry's needs for research, resource assessment, and performance validation. Energy production and observation data will be tracked online. This will allow us to study how water and air temperatures affect energy production.
Figure 14.

Monitoring of floating photovoltaic systems. Floating solar stations, like other energy stations, can be operated from the dispatcher center using SCADA. Computer software have been developed for this purpose. The software includes parameters such as solar radiation, energy production, water and air temperature. Data can be both archived and used for comparative analysis. (Figure 15 and Figure 16).

Converter level monitoring

Figure 15

Power plant level

Figure 16

Conclusion. When combined with other demonstrated benefits such as higher energy yield, reduced evaporation, and improved water quality, floating solar is likely to be an attractive option for many countries. The development of floating solar stations in Azerbaijan is a requirement of the day. I think it will be possible in the near future. In fact, it would be better to pay more attention to the installation on the water than to install it on the ground. I think that there are favorable conditions for the development of floating solar technologies in our country. It would give good results, especially in the Karabakh region.

https://www.nsenergybusiness.com/news/floating-solar-can-open-up-new-horizons-for-renewable-energy-says-world-bank/#

https://www.scheuch-foundation.org/en/swimsol-solarsea-the-worlds-first-floating-solar-power-plant-for-the-sea/

https://www.solarpowerworldonline.com/2020/01/new-jersey-town-keeps-its-water-clean-with-the-countrys-largest-floating-solar-system/

https://www.hahasmart.com/blog/2988/floating-solar-advantages-and-disadvantages

https://olc.worldbank.org/system/files/131291-WP-REVISED-P161277-PUBLIC.pdf

«Floating Solar Energy Development Project» Capacity building web trainings First and Second Week. Proqram (Nov. 30 – Dec. 3, 2020), Dec. 14-Dec.17) (Baku, Azerbaijan)

Mammadov Rasim – Azerbaijan Renewable Energy Agency.
Chief Metrologist of "Azalternativenergy LLC".
Azerbaijan Civil Engineering University -Bachelor degree in field of "Water supply and water protection".
Ukrainian National Technical University, Kharkov Polytechnic Institute-Master's degree in field of "Electromechanics and Automated Systems". He holds various positions on a repair and adjustment of the remote control of the measurement devices, wind measurement observation stations, solar monitoring stations, remote sensing systems, solar water pump systems, solar and wind powered hybrid stations, service to wind turbines in “Azalternativenergy” LLC. He has successfully participated in advanced training courses on control and measuring devices and automation, automation systems in a number of countries around the world, including the United States, Germany, Singapore, the Philippines, Turkey, France, Greece, Belgium and our country. He has successfully completed courses and received certificates from the following companies to operate in the relevant field. German companies Elster GmbH, Ammonit Measurement GmbH, MVV Decon. “Singapore Environment Institute. Council of Europe “EU and TACIS Manager Training Program”. Argon National Laboratory, co-organized by the Government of the Philippines and ADB. European International Business Institute and EU-SIM4NE. Quality Association LTD and Baku Computer Lyceum of the Republic of Azerbaijan. In November and December 2020, he participated in a 2-week training program "Development of floating solar power plants" organized by the Ministry of Energy of Azerbaijan and ADB.

Presentation:

1. Monitoring of the Renewable Energy Sources in Azerbaijan
https://www.unece.org/fileadmin/DAM/energy/se/pp/gere/gere.3_Baku.Oct.2016/20_IRENA_CIS/Rasim.Mamedov.pdf
2. Solar water pumping and smart irrigation system for Azerbaijan.
http://area.gov.az/news/146)
Article: Solar water pump systems and application
https://archive.org/details/eee-c-v-9-2-p-70-1/page/56/mode/2up

UOT 621.1

METHODS OF OBTAİNİNG ELECTRİCİTY FROM RAİNWATER

R.K.Kalbiyev*, R.R.Jamalova**
***Azerbaijan State Oil and Industry University**
****Rainergy**

Annotation. The Rainergy designed to produce electricity from the rain to solve the problem of energy deficiency in the rainy and low-income countries. Rainergy collects rainwater and uses it to produce electricity. It transfers the rich potential energy of rainwater into electricity through the motion created by the wheel. Then the electric energy stored in the accumulator for the further implementation.

Key words. Renewable energy, Rainergy, rainwater, piezoelectric generator, “Pluvia” technology.

1. Introduction

Energy from rain is an important source of clean and green energy. At a time when demand for energy is growing and countries are sensitive to global climate change, the expansion of energy sectors, including rain energy, has gained value, especially in developing countries. Like solar, wind, biomass and other alternative and renewable energy sources, rain energy also has positive properties - it is economically feasible, has minimal impact on the environment, reduces energy losses and waste, and increases efficiency. Solar, wind, biogas and geothermal energy sources have been extensively studied and there are large-scale power plants for their implementation. So, there is a demand for detailed research and application of energy production from rain.

In modern times, energy security, the constant rise in fuel and energy prices increase the importance of renewable energy sources. In the world, searches are being carried out in the direction of obtaining cheap and sustainable energy, various types of renewable energy are being applied in combination, new technologies in the field of energy conservation as well as the use of hydrogen are expanding. One of the advantages of obtaining energy from rain is that it can be used directly in the area where it is obtained, namely there will be no need for long-distance transmission and additional losses. Although this amount of energy is small when produced in individual homes, in general, the scale will increase as the energy generated in the home is concentrated. In solar energy, the average capacity of a solar panel is 250-350 W, but at present, solar power plants with a capacity of gigawatts have been launched in the world. As can be seen, the energy from the rain will be gradually expanded and applied to various sectors of the economy.

Although less energy is obtained from rain than other types of renewable energy, energy obtained from water (hydroelectric power plants, wave energy, traction energy) is widely utilized in the world. The following table presents the development indicators of renewable energy sources in 2010-2019:

Table 1. Total renewable energy

CAP (MW)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
World	1 226 853	1 332 236	1 445 233	1 563 196	1 692 680	1 846 060	2 008 547	2 182 449	2 361 061	2 536 853
	Hydropower									
	1 024 833	1 055 557	1 088 563	1 135 510	1 174 396	1 210 496	1 245 469	1 275 538	1 297 465	1 310 292
	Renewable hydropower (including mixed plants)									
	925 077	952 564	982 946	1 028 654	1 065 799	1 098 643	1 128 527	1 155 689	1 176 969	1 189 448
	Pure pumped storage									
	99 756	102 993	105 617	106 856	108 597	111 853	116 942	119 849	120 496	120 844
	Marine energy									
	250	503	509	510	513	513	524	528	529	531
	Wind energy									
	180 850	220 020	266 909	299 920	349 300	416 276	466 827	514 402	563 820	622 704
	Onshore wind energy									
	177 794	216 244	261 575	292 749	340 808	404 558	452 485	495 565	540 191	594 396
	Offshore wind energy									
	3 056	3 776	5 334	7 171	8 492	11 717	14 342	18 837	23 629	28 308
	Solar energy									
	41 542	73 734	104 078	139 582	176 018	221 993	295 821	388 557	488 752	586 434
	Solar photovoltaic									
	40 277	72 030	101 511	135 740	171 519	217 243	290 961	383 598	483 078	580 159
	Concentrated solar power									
	1 266	1 705	2 567	3 842	4 499	4 750	4 860	4 959	5 674	6 275
	Bioenergy									
	65 626	71 795	76 611	83 812	89 891	96 822	104 594	110 571	117 740	123 802
	Solid biofuels and renewable waste									
	54 251	58 459	61 430	67 809	72 554	78 753	85 615	90 070	96 170	101 138
	Bagasse									
	10 557	11 688	12 840	14 577	15 533	16 858	17 588	18 213	18 897	18 997
	Renewable municipal waste									
	6 679	6 824	7 287	8 394	8 631	10 024	10 808	11 788	13 110	14 518
	Other solid biofuels									
	37 015	39 947	41 303	44 838	48 391	51 871	57 219	60 068	64 162	67 623
	Liquid biofuels									

1 857	1 907	2 066	2 041	2 338	2 419	2 322	3 233	3 211	3 211
Biogas									
9 518	11 429	13 114	13 962	14 999	15 650	16 656	17 268	18 359	19 453
Geothermal energy									
9 992	10 081	10 481	10 718	11 159	11 814	12 255	12 700	13 249	13 931
Off-grid capacity Total renewable energy									
4 125.200	4 568.774	4 989.040	5 426.469	6 359.079	7 059.187	7 703.771	7 680.325	8 433.816	8 593.947
Hydropower									
614.642	626.901	665.141	681.063	694.106	732.195	739.66	772.361	792.521	823.491
Solar photovoltaic									
381.582	498.377	711.97	1 048.240	1 318.469	1 698.149	2 174.743	2 784.316	3 321.011	3 432.799
Other renewable energy									
3 128.976	3 443.496	3 611.929	3 697.166	4 346.504	4 628.843	4 789.368	4 123.648	4 320.284	4 337.657

IRENA (2020), Renewable capacity statistics 2020

2. Selection of scientific direction of the project and brief review on the proposed scientific problem

2.1. The purpose of the project

The aim of the project is to obtain energy from rain in rainy areas, to study the increase of efficiency in acquiring energy with the application of new technologies, to develop and test the rain generator.

The project will conduct fundamental and applied research, electricity will be generated using rain generators to meet the energy needs of public, social and other buildings located in different areas, modern equipment will be used to transfer the remaining energy to the general network, to ensure the normal operation and management of the system. Power supply equipment with a rain generator will be selected and justified according to the location of the buildings, the rain potential of the area and the dimensions of the buildings.

2.2. Relevance of the project and raised issues

The energy available from rainwater is renewable energy sources (RES). The proposed project can be implemented in rainy areas, residential and public buildings, greenhouses and other areas where rainwater can be collected. The project will use high-efficiency technologies in the development of equipment used for energy generation. The project will allow the use of environmentally friendly RES, the use of new technologies will develop innovative infrastructure, as well as allow the commercialization of modern technologies by expanding the application.

One of the difficulties in applying energy from rainwater is the connection of the generated energy to the general network. It is known that this difficulty prevents the widespread use of RES generation forces. The reason for this is shown as the intermittent generation of some types of BEM power, the instability of energy parameters. Overcoming these difficulties with the use of new technologies will be reflected in the project. During the implementation of the project, fundamental research will be conducted, and proposals will be prepared for the transfer of small forces to the general network, either collectively or individually.

Also, there will be no need to transport rain-generated energy over long distances. One of the most important aspects of this method will be the enlightening feature, then it will be an example for application in other areas, such as agriculture, health, etc., to promote and stimulate innovation.

2.3. Atmospheric precipitation

Many parts of the world receive heavy rainfall throughout the year. The first such place is the Mauzinram region in northeastern India. The region, which is included in the Guinness Book of Records, receives an average of 11,871 mm of rainfall per year. The region has natural green forests, numerous waterfalls and caves created by waterfalls on rocks.

The second region on the list is Sohra, a few kilometers from Mauzinram. The annual rainfall in this region is only 100 mm less than in Mauzinram. However, the Sohra region maintains the record for the rainiest month and year. Thus, in July 1861, equal to 9,300 mm, in August 1860, it was recorded as the most sensitive place with 26,470 mm of rain to date. People living in these parts of the Indian state of Meghalaya always walk around with umbrellas made of cane.

One of the rainiest countries in the world is Colombia. Lloro in the northwest of the country recorded 13,474 mm of rain in 1952 and 54, respectively. However, due to the use of old measuring instruments, these official records are not taken into account.

Annual rainfall in the Puerto Lopez region near the Andes is 12,892 mm. However, it is not possible to compare it with other regions, as the amount of precipitation has not been measured in some years.

Atmospheric precipitation in the Republic of Azerbaijan is mainly due to the intrusion of air masses into the area. The amount, season and annual distribution of precipitation are determined by the interaction of air masses with the terrain and the Caspian Sea. For comparison, the lowest average annual rainfall in Azerbaijan (less than 150-200 mm) falls on the south-eastern Gobustan and the southern coast of the Absheron Peninsula. It is 1400-1600 mm on the southern slope of the Greater Caucasus, 800 mm on the north-eastern slope, 800-900 mm in the Lesser Caucasus and Nakhchivan AR, and 1700-1800 mm in the Talysh mountains. The highest daily maximum precipitation was recorded on the southern slope of the Greater Caucasus (148 mm, Alibey) and the Talysh Mountains (334 mm, Belasar). The intensity of torrential rains reaches 1-2 and even 3 mm per minute.

2.4. Stages of the project and areas of application

There are many ways to get energy from rain. It covers various areas such as labor, engineering, finance, law and management.

First, the site for the application must be selected. Then the following technological issues should be solved step by step:

- The topography and structure of the area is described;
- Rain reserves and its energy production potential are assessed;
- Scheme and location plan of facilities in the area is developed;;
- Hydraulic turbines and generators, their control;
- Environmental impact assessment and mitigation measures;
- Economic evaluation and financing potential of the project;
- Institutional framework and administrative procedures are conducted to obtain the necessary consent.

In buildings where a rain generator is used, it is possible to provide part of the electrical loads to illuminate the facades and areas of the buildings.

It is pointless to create an independent power supply system through batteries if the buildings have access to a centralized power supply network. In this case, you will first need to charge the batteries during the rainy hours, and during the rainy hours you will need to discharge them to equip the lamps. This has several serious shortcomings, and it is possible to eliminate these shortcomings in areas with centralized power supply. In places with centralized power supply, if rain generators are used in the "ten grid" system, there will be no need for electric accumulators.

These are the additional advantages of lighting systems based on rain generators in stairwells, elevator zones and technical areas in buildings:
- comfort of residents and technical staff;
- reducing the risk of injury to residents in the dark;
- crime prevention;
- no payments for electricity;
- more economical than traditional lighting systems;
- the equipment does not require regular maintenance;
- environmentally friendly source of electricity.

The scheme of connection of rain generators in the buildings to the general network is given below:

Figure 1. Scheme of connection of the rain generator to the electric network

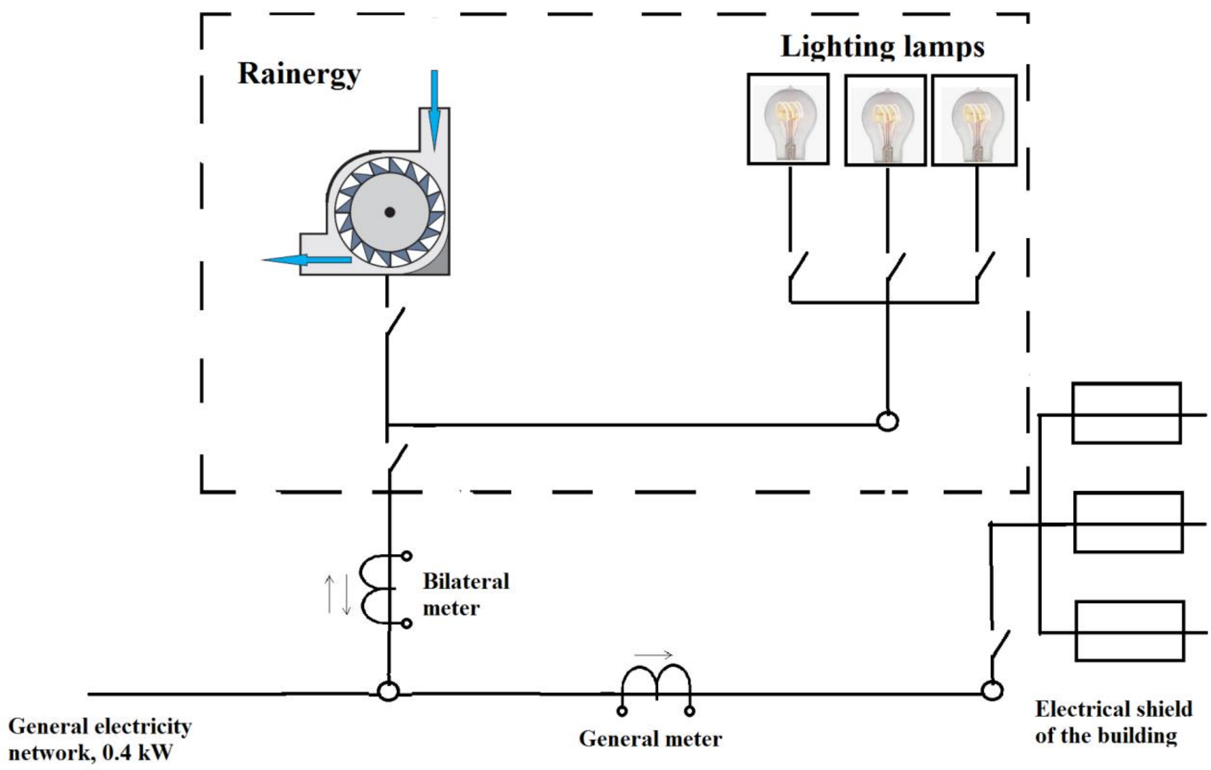


Figure 1. Scheme of connection of the rain generator to the electric network

2.5. Comparative overview of methods of obtaining energy from rain

The proposed method of obtaining energy from rain (Rainergy) has been used by scientists from around the world. However, these methods differ from the project we present in terms of structure, technological equipment, etc. The technological sequence of energy conversions in the project we present is as follows [1]:

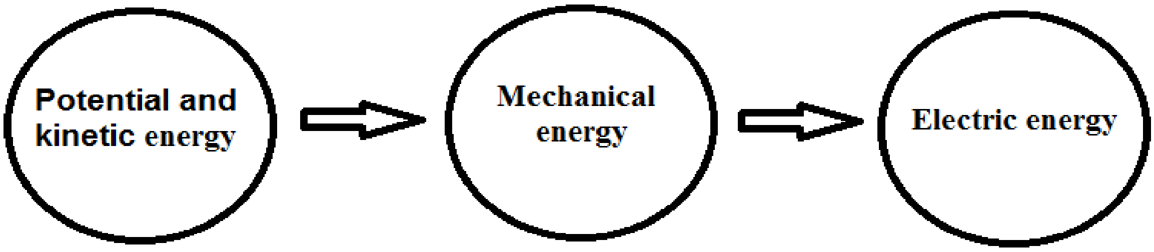


Figure 2. Energy conversions in the method of obtaining energy from rain

Studies show that billions of tons of rainwater are produced in the world during the rainy season. It has great potential if used properly. Rainergy is designed to generate electricity from rain to solve the problem of energy shortages in rainy countries. Rainergy collects rainwater and uses it to generate electricity. Transfers the kinetic and potential energy of rainwater to electricity through the motion created by the wheel. Electricity is stored in the battery for later use.

Our device consists of 4 main parts. The rainwater collector fills the reservoir with rainwater, then the rainwater passes through the electric generator at high speed and electricity is generated in the generator by the action of a small hydro turbine. 3 prototypes of the device were prepared and tested in the laboratory. Our first prototype was able to illuminate only 3 LED lamps, the second prototype was able to illuminate 22 LED lamps. In our third and final prototype, developed by AREA specialists, the rotor speed was 180 cycles per minute and power was 120 W. In addition, it reduces CO2 emissions such as Rainergy, Solar plants, Wind plants and other AREA power generating units.

One of the similar projects are devices presented by Indian scientists. In one of the similar projects are devices presented by Indian scientists. The aim of this project is to use the energy stored in rainwater to power buildings in the regions that are experiencing power outages during the summer months. This can be achieved by using a structured special piping system, an individual small-scale generator turbine and piezoelectric generators to use the kinetic energy of the falling water.

These devices can be used to generate energy from rain in residential buildings in areas with high rainfall. These devices can be used as a good alternative in areas where solar energy is difficult to use. The following figure provides a brief diagram of this project:

Figure 3. Energy conversions in piezoelectric generators

This system converts the energy of raindrops into electricity in the in the way given below:

Piezoelectric materials are used to generate electricity from the kinetic energy of raindrops. The physical properties of piezoelectric materials allow them to generate electricity. This feature is known as the piezoelectric effect. When there is a compressive or tensile stress in these materials, an electric field is created across the material and a voltage difference occurs resulting in current flow. The occurrence of this voltage difference is due to the asymmetric nature of the crystal shape (cells) of those materials. As can be seen from the figure, a small part of the crystal form (cell) is positively located in the form of a particle in the center. When a certain compressive force is applied, this particle slides in a certain direction, distributing the load and then creating an electric field. These materials come in different forms. The most common are crystals, but also substances such as plastics and ceramics are also found.

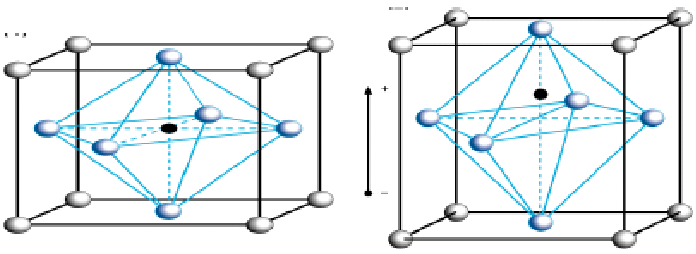


Figure 4. Crystal lattice structure of piezoelectric materials

The power generated by the above method is stored in electric batteries and can be used during power outages.

Mexican University of Technology students offer small-scale hydroelectric solution that can be used in areas without extensive infrastructure. The new technology, called “Pluvia”, is a winged micro turbine integrated into a house's half-inch (13mm) diameter single-pipe discharge system (built into the system, so there is no need to install an additional pipe system in homes). The rain is collected and stored, pumped to the water tank and then passed through a micro turbine. When the turbine rotates, current is generated and usable electricity is obtained.

Figure 5. Extraction of energy from rain by “Pluvia” technology

However, according to some estimates, the pump mechanism currently needs more power than the electricity produced by the turbine. In other words, the system cannot work without a pump.

This small turbine is suitable for families who cannot afford convenient, reliable electricity, even though it can charge portable 12-volt batteries, which are enough to run only LED lamps. So far, Pluvia has been tested in the Iztapalapa community of Mexico [8].

This research is valuable as a start. Although this time it is not practical, photovoltaics or wind turbines can be placed on the roof to power the pump. These strategies will initially cost more to install, but can lead to useful results as technology advances.

Solar panels that produce energy from rain and sunlight have been produced. Solar cells receive energy from both the sun's rays and raindrops. The practical application of this innovation is not widespread. A hybrid device has been created that collects kinetic energy in rainwater along with solar energy by drawing a nano surface on the solar panels. The new device is designed to prevent a decrease in energy output when the sun is dim [2].

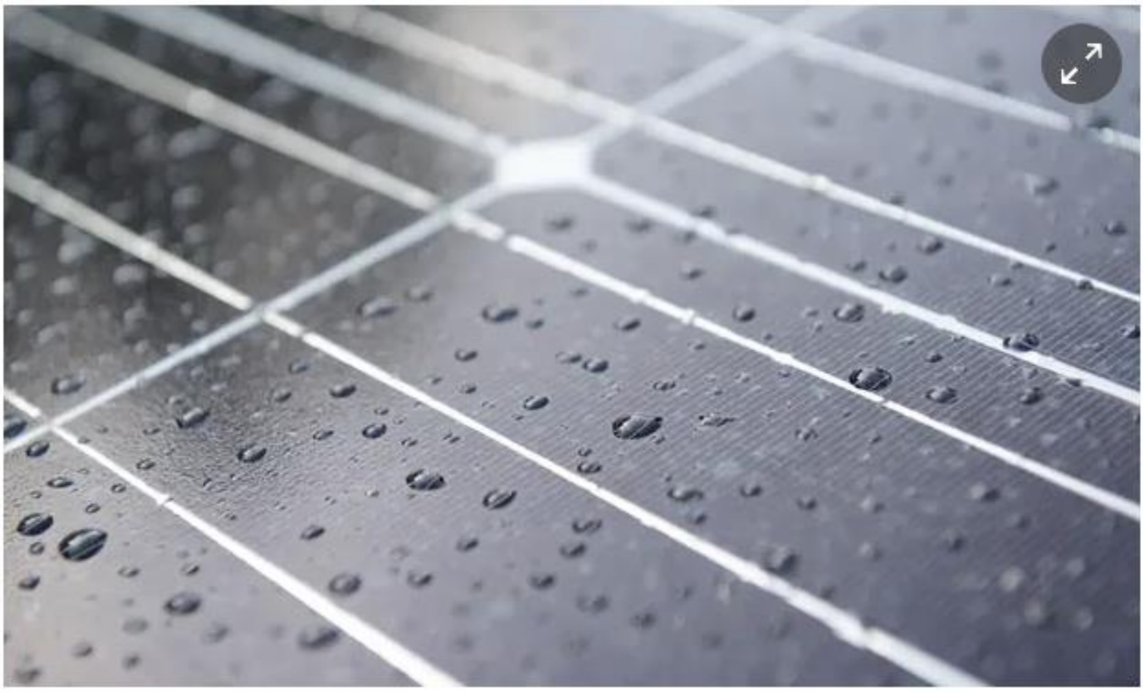


Figure 6. Hybrid device that collects kinetic energy from rainwater along with solar energy.

A solar panel that can generate electricity from raindrops allows it to produce energy even in cloudy weather and at sunset.

Thanks to a 90% reduction in the cost of solar power plants over the past decade, their use is steadily increasing and is becoming the cheapest electricity in many parts of the world. However, electricity can drop in gloomy weather, and researchers are trying to get more electricity from panels in such weather.

Demonstrated in a laboratory at Soochow University in China, the new device placed two transparent polymer layers on top of a solar photovoltaic (PV) cell. When raindrops fall on layers and then roll, they create a static electric charge without friction.

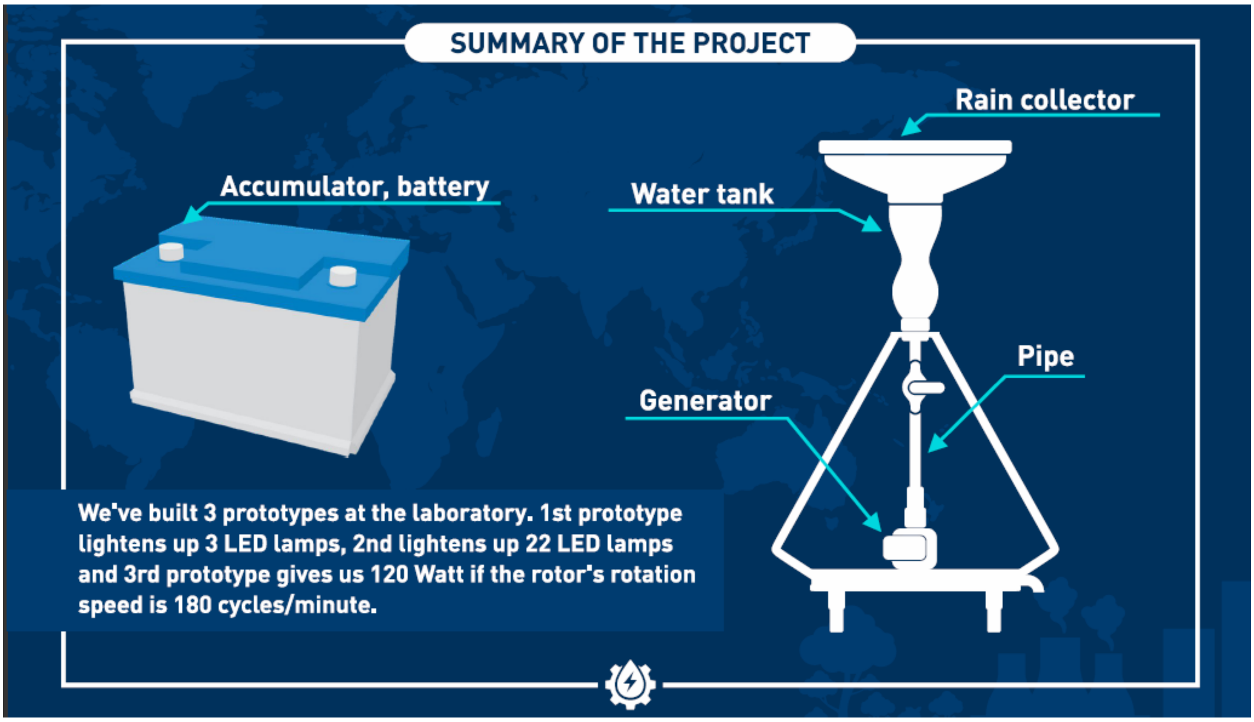
Baoquan Sun from Soochow University said, "The device can generate electricity in any weather conditions. In addition, this device will generate electricity if it rains at night."

Other researchers have recently developed similar devices in solar panels known as triboelectric nanogenerators (Tengs). The proposed new design is significantly simpler and more efficient, as one of the polymer layers acts as an electrode for both Teng and the solar cell.

Baoquan Sun reported that the industry is developing rapidly and a new prototype product will be produced in 3-5 years. Other Chinese scientists also used the Tengs to get energy from the wind in solar cells. The top layer of the teng is also threaded to help direct more light into the solar cell. For the devices presented, Professor Keith Barnham of Imperial College London commented that the hybrid device has a significant advantage in being more compact and efficient.

2.6. Project of rainenergy (Rainergy)

The device works by collecting rainwater and then sending it through a high speed generator which produces energy. The energy can then be stored, which relieves pressure on the local power grid by providing communities with an additional source of electricity [7].

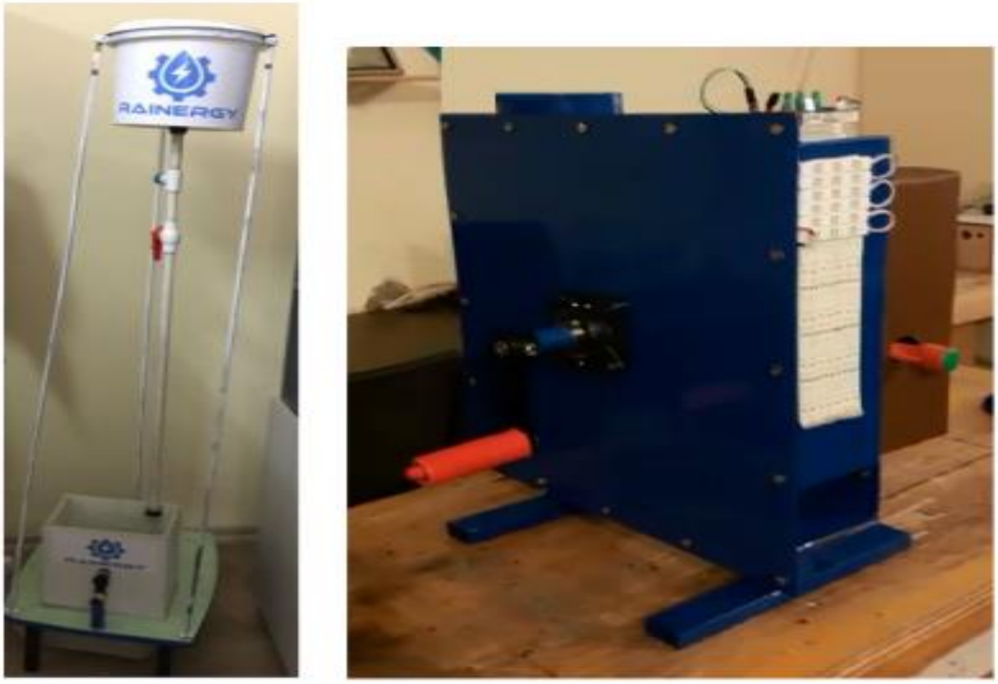


Pic. 7. Scheme of accumulation of energy produced from rain.

The nine-meter-high instrument consists of four main parts: a rainwater collector, a water tank, an electric generator and a battery. The collector fills the reservoir with rainwater that will later flow at high speed through the generator to produce energy. The generated energy is stored in the battery, and can relieve pressure on the local power grid by providing communities with an additional source of electricity. The team has developed two prototypes. One lights up three LED lamps while the other produces enough electricity to light 22 LED lamps for up to 50 seconds using only seven liters of rainwater. Jamalova says that underprivileged communities can use Rainergy to power items such as street lamps.

Rainergy's competitors for renewable energy include solar panels, wind turbines and piezoelectricity (which results from subjecting some solids to mechanical stress). Most of these alternatives require substantial investment, labor, and energy or electricity experts to build and operate them, whereas the Rainergy device has a relatively simple design.

"Our model is much more efficient in comparison with similar systems," explains Jamalova, noting that piezoelectric rain generators produce only 25 microwatts of power. Rain-harvested energy emits 10g/kwh of CO2 during electricity production, which Jamalova claims is "very low compared to alternative energy solutions."



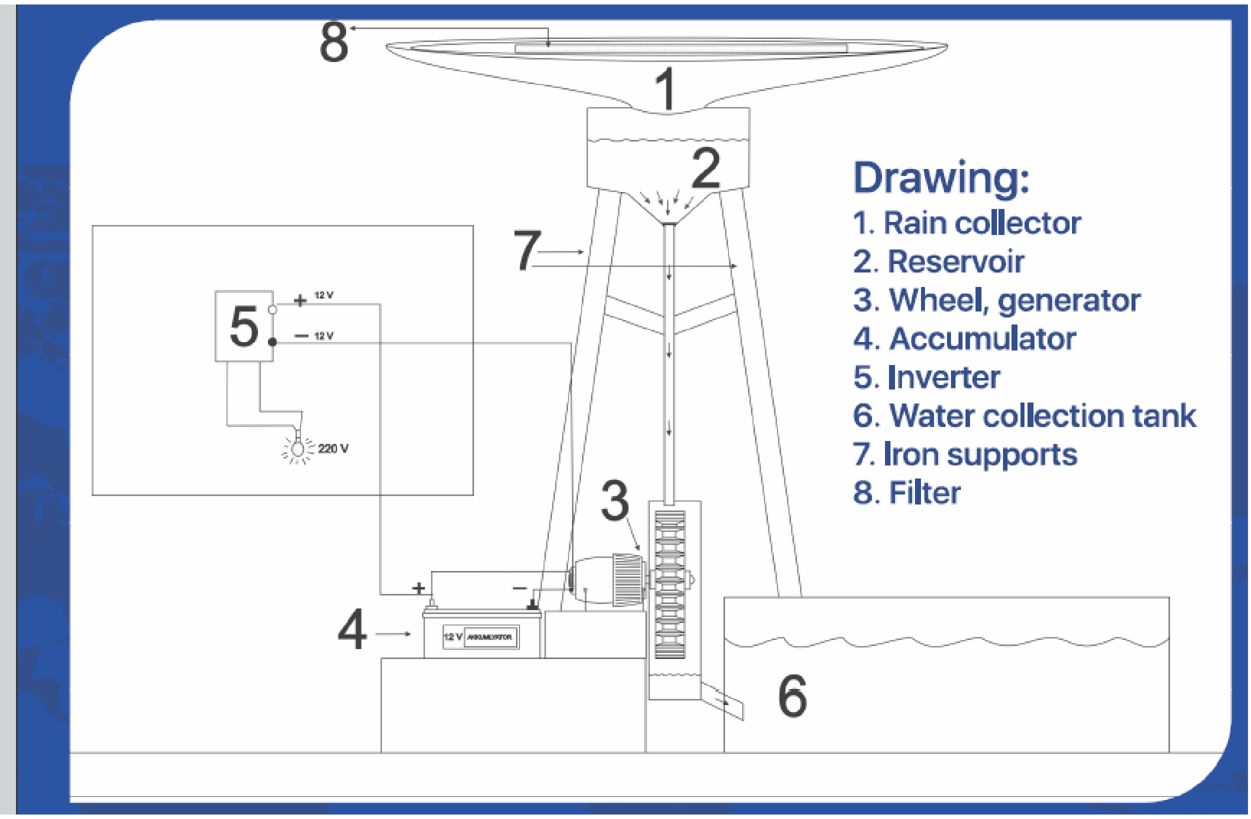
Pic. 8. General views of Rainergy

Another advantage of the Rainergy device is that it stores energy in a battery, so that it is effective even when there is no rain.

Rainergy was first presented in the ClimateLaunchpad competition and won "Audience favorite startup" award in national final. Then it was represented globally at the Global Summit of Entrepreneurship in India in November 2017.

While Rainergy's creators originally conceived of the device for regions of Azerbaijan with the heaviest rainfall, they are aiming to market it internationally – especially since, as Jamalova says, "Azerbaijan is not a rainy country." In countries such as the Philippines, India, Malaysia and Indonesia, where monsoon rains are frequent, this device could be a perfect solution for reducing dependence on power lines and improving access to electricity. 21 percent of the population in India and 11 percent in the Philippines lack access to electricity, according to the Global Tracking Framework 2014 report. "In the future, we want to create a business based on this device," says Jamalova. For now, the invention has landed its young creator on Forbes 30 Under 30 Asia list 2018 – the first Azerbaijani person in history to make the rating."

The project revenue model has been proven in local and global markets, such as a sustainable and up-to-date business model. Currently, the project is supported by the Republic of Azerbaijan and the Islamic Development Bank. Indeed, Rainergy became one of the 32 winners this year, among the 1570 projects of the Transform Fund held by the Islamic Development Bank for the first time, and it has featured in the world-famous business magazine Forbes as an economically-socially profitable project.



Pic. 9. İnstallation scheme of Rainergy.

References

1.Aashay Tinaikar. Harvesting energy from rainfall. International Journal of Renewable and Sustainable Energy 2013; 2(3): 130-132

2.Curt Harting, “Rainfall as an Energy source”, Physics 240, Stanford university, November 2010

3. Askel Bode. “Harvesting Rainfall”, , Project 1, Phys575, 14th February 2012,

4.Andrew Katz “Residential Piezoelectric Energy Sources”, , delta smart house, 21st July 2004.

5.Lisa Zyga. “Rain power: Harvesting Energy from sky”, , January 2008.

6.Micka¨el Lallart,_ Shashank Priya, Scott Bressers and Daniel Inman, “small scale piezoelectric energy harvesting devices using low energy density sources”, Journal of Korean Physical society, vol 57, no 4, pp. 947-951, October 2010.

7.www.rainergy.co

8.**https://doi.org/10.3390/atmos11030282**

YAĞIŞ SULARINDAN ELEKTRİK ALMA ÜSULLARI

R.K.Kəlbiyev *, R.R. Camalova**

*** Azərbaycan Dövlət Neft və Sənaye Universiteti**
**** Rainergy**

Annotasiya

Rainergy, yağışlı və az gəlirli ölkələrdə enerji çatışmazlığı problemini həll etmək üçün yağışdan elektrik enerjisi istehsal etmək üçün dizayn edilmişdir. Rainergy yağış suyunu toplayır və elektrik enerjisi istehsalında istifadə edir. Yağış suyunun zəngin potensial enerjisini çarxın yaratdığı hərəkət ilə elektrik enerjisinə çevirir. Daha sonra istifadə olunmaq üçün elektrik enerjisi akkumulyatorda toplanır.

Açar sözlər. Bərpa olunan enerji, Rainergy, yağış suyu, piezoelektrik generator, “Pluvia” texnologiyası.

Renewable Energy Agency under the Ministry of Energy of the Republic of Azerbaijan

Senior advicer of Department of İmplementation and monitoring of projects – Kalbiyev Ramiz Kalbi

Born in 1966

Graduated the Azerbaijan University of Architecture and Construction with the direction of engineer mechanician in 1990.

Started its labor activity at the Azerbaijan University of Architecture and Construction in 1990.

Since 2007 has worked as assistant professor of the Azerbaijan University of Architecture and Construction.

Since 2011 has worked as adviser of Ministry of Energy.

Since 2013 has worked as deputy head of department of State Agency for Alternative and Renewable Energy Resources of Industry and Energy Ministry of Azerbaijan Republic.

Since 2018 has worked as deputy head of department of State Agency for Alternative and Renewable Energy Resources.

Since 2020 has worked as head of department of State Agency for Alternative and Renewable Energy Resources.

From October 15, 2020 has appointed senior advicer of State Agency for Renewable Energy Resources of Energy Ministry of Azerbaijan Republic.

Doctor of philosophy for Mechanical Sciences.

Married. Has 4 children.

Project Manager, Rainergy – Jamalova Reyhan Rauf

Reyhan Jamalova is 18-year-old founder of Rainergy—a company that aims to solve the energy deficiency problem in rural parts of rainy countries by providing their communities with clean, sustainable, and alternative rain energy.

As the youngest female entrepreneur in the Global Entrepreneurship Summit India in 2017, her work was acknowledged by Ivanka Trump, who repeated her motto "Light up one house at a time" on stage to thousands of people.

As a result of Rainergy's success, Reyhan was selected for the Forbes 30 Under 30 List in Asia as the first Azerbaijani, placed on BBC's 100 Most Influential and Inspiring Women List of 2018, and invited to international conferences as a keynote speaker. Reyhan is a 2018 Presidential Youth Award holder, 2019 TRT World Youth Award winner, the Global Good Fund 2020 Fellow, bp NetZero Scholar, and One Young World Ambassador.

In addition to bettering the lives of many struggling families with Rainergy, Reyhan convinced the people in her country to believe in their daughters' potential, worth and dreams with her own accomplishments.

Assessment of Power System Flexibility

Prof Yusifbayli N.A[1], Aghaliyev N.N

[1] Deputy chairman of the State Agency on Alternative and Renewable Energy Sources

[1] Phd student of Azerbaijan Technical University

Abstract. As the Power systems are evolving to the networks with proliferated penetration of renewable energy resources, planning for the effects of variability will become more important. Plus due to the stochastic nature of renewables, the management of the rapidly increasing uncertainty and variability in power system planning and operation is of crucial significance. Traditional capacity adequacy planning techniques have been supplemented with integration studies, which have been effectuate in power systems with high targets for renewable generation. These have highlighted the proliferated variability that a system may experience in the future. As system generation planning techniques evolve with the challenge of integrating variable generation, the flexibility of a system to manage periods of high variability needs to be evaluated. The insufficient ramping resource expectation (IRRE) and the loss of load expectation (LOLE) metrics are proposed to measure power system flexibility for use in long-term planning, and are derived from traditional generation adequacy metrics. Compared to existing generation adequacy metrics, flexibility assessment is more data intensive. A flexibility metric can identify the time intervals over which a system is most likely to face a shortage of flexible resources, and at the same time can measure the relative impact of changing operational policies and the addition of flexible resources. The flexibility of a test system with increasing penetrations of variable generation is assessed and the results highlight the time horizons of increased and decreased risk associated with the integration of variable generation (VG).

Keywords: The insufficient ramping resource expectation, the loss of load expectation, flexible resources, operational policies, variable generation, demand side resources.

Introduction: Tuday generation portfolios of many power systems are changing significantly in a way that relates to the whole world. Taking into consideration the environment and energy security, as well as rising fuel prices, have led to significant, sustained growth of wind and solar electricity generation capacity globally. Wind, solar, hydro and tidal, generally variable generation (VG) can be defined as those resources whose output is dependent on the prevailing environmental conditions. The difficulty posed by the integration of these variable resources into existing power systems varies according to the production and scale of the variable resource, its correlation with system load, and the flexibility of the energy system [1]. Flexibility is defined as the ability of an energy system to deploy its resources to reflect and respond to changes in net load, where net load is defined as the remaining system load not served by variable generation. On that account, an isolated power system containing mostly generation units with long start up times and low ramp rates will face difficulty to successfully integrate variable generation. An emerging challenge in power system planning is to evaluate the ability of an existing power system to successfully integrate a targeted penetration of variable generation (VG), and thus to plan future portfolios [2]. The purpose of this paper is to highlight the need to evaluate flexibility in generation planning, examine current planning practices and propose an adaptation of existing reliability techniques to measure flexibility affairs. Therefore, understanding of system flexibility will become very important in a planning context.

In energy systems where the ramping requirements can be forecast accurately in advance, system flexibility may not be as critical to a system planner. For instance, where the daily morning rises dominate the requirement for flexibility over all time horizons, current planning practices are likely sufficient. Since the construction of new generation facilities has a multi-year lead time, so traditional long-term planning is required for ensuring the future reliability of power system. This affair is normally carried out for long time horizons on a rolling annual basis, by either regulators, system operators or utilities, depending on the system types [3]. Generation adequacy studies have faced the question of how much capacity is required to reliably meet system load at a certain point in time, but have not considered whether the system's planned resources could be operated in a sufficiently flexible manner or not. Identifying of how much generation capacity and what types of characteristics that capacity should have are key tasks for regulatory bodies and who look to ensure that market designs deliver in the long run or for vertically integrated utilities or ensuring the suitability of a planned plant portfolio before more detailed engineering and operational analyses are carried out. Plant manufacturers and investors also have an huge interest in the cycling requirements that experienced by potential investment.

Planning for Generation System: Generation planning studies have developed due to the reason that the targeted penetration of variable generation has increased in the world power systems. Traditional metrics for reliability have been added by variable generation (VG) integration studies. In long-term generation planning, the inclusion of operational practices is a developing trend, leading to an additional new stage in the planning process [4], [6]–[8]. There are three types of approaches and stages in the planning process.

a) Capacity adequacy planning: Generation adequacy metrics, such as the expected energy not served (EENS), loss of load expectation (LOLE) [9], [10] or well-being analysis [5] are standard measures by which a planned portfolio is evaluated and have served for industry well so far. Some general assumptions are made by these methods, but the primary assumption being that load shedding will only occur during the times of insufficient capacity and plus either of generation or of transmission. The methods include a reserve criterion by which operational constraints are included. Deterministic criterias such as fixed capacity reserve levels are based on heuristics and simple to implement, and so subsequently in long-term planning studies many power systems employ deterministic criteria exclusively [11]. The capacity margin can be set in planning studies using probabilistic methods such as an loss of load expectation (LOLE), or deterministic metrics such as the loss of largest unit (LLU) target. Both probabilistic and deterministic criterias are considered by well-being analysis in evaluating the adequacy of the planned system's resources, and results in a set of indices which describe the system's adequacy as one of three outcomes: marginal, healthy or at risk [10]. System load, veriable generation (VG) forecast errors and the outage of generation resources are the main causes of unpredicted ramping events. With the development of proliferated penetrations of VG, significant uncertainty surrounds the future ramping requirements of a power system. Additionally, peak net load forecasting is dependent on VG forecasts, are potentially challenging the assumption that a system operator will have sufficient forewarning to prepare generation resources. In the end, challenges have arisen in establishing the contribution to the generation capacity adequacy of a system by the integration of veriable generation (VG) [12]. Hence, new long-term planning methods (which incorporate variable generation and variable generation forecasts) have been developed and are leading to the development of VG integration studies.

b) Integration studies: Integration studies have been accomplished for many different kind of power systems pursuing a high penetration of variable generation [7], [8], [13], [14]. The main purpose of these studies have tended to focus on understanding that how VG will impact on the daily operation of a power system and the transmission reinforcement required by employing production cost models [8]. Integration studies have required modeling tools and enhanced simulation. The adaptation of unit commitment to a stochastic [15] and rolling framework, and the inclusion of VG forecasts [3] can provide an insight into how systems might operate under high VG penetrations. Operating reserve is typically planned for on a day ahead basis, to ensure that the planned quantities match the generation resources available [9]. Current practice presents probabilistic methods [7] over traditional deterministic methods [11], which try to calculate the ‘correct’ amount of operating reserve for a power system.

Integration studies require extensive data and computation to produce indicative results of future power system operation and are dependent on a proposed generation portfolio and transmission network, which is in turn dependent on a capacity adequacy study. Therefore, portfolio development is an iterative process in order to produce the least cost optimal generation portfolio. The inclusion of a system flexibility assessment stage, before proceeding with integration studies, may expedite the planning process by identifying the characteristics of resources which are required by a system, (Figure1)

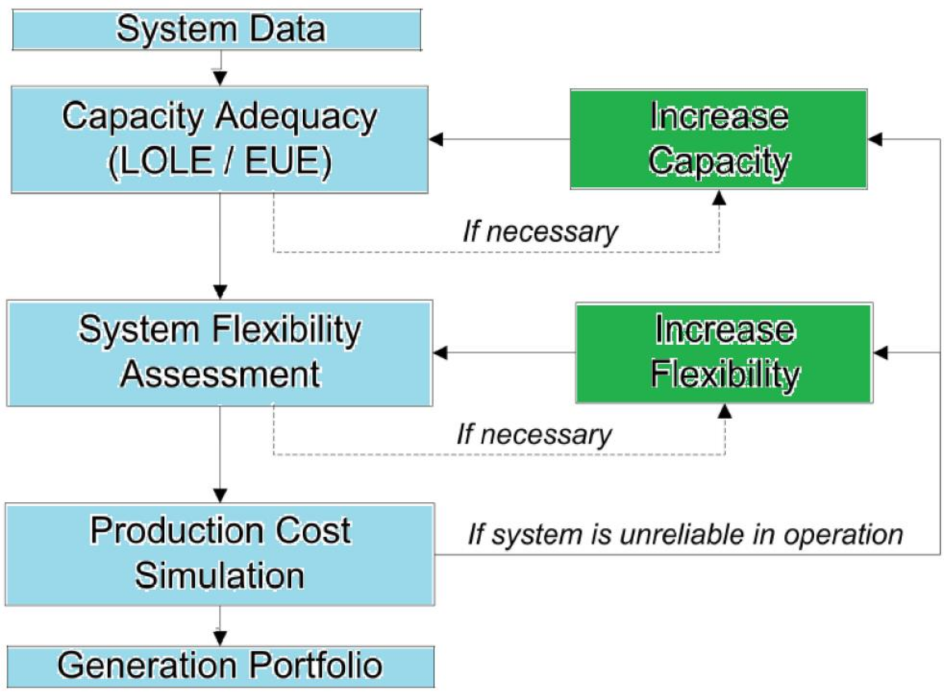


Fig. 1. Development of generation planning scenario

c) Long-Term Planning for Flexibility: System load forecasting, VG forecasting, establishing planned closures and construction of resources, capacity expansion studies and adequacy calculations are currently key tasks for long-term planning.

A new planning metrics are required to measure the flexibility of a system, in the same way as the loss of load expectation (LOLE) measures the capacity adequacy of a power system with respect to operational constraints. An overall understanding of how well a system can manage predicted and unpredicted changes in the net load over a wide variety of time horizons will ensure that the results from long-term generation planning are robust when VG is integrated into a power system. Current planning methodologies, such as in [5], produce portfolios with sufficient flexibility implicitly in a context of low penetrations of variable generation. However, an explicit understanding of, and planning for, the challenges posed by the flexibility required by high penetrations of VG is missing from long term planning methodologies. A useful system flexibility metric should try to achieve the following:

a) Quantify the ability of a system to respond to short-term changes in system load, VG, and generation unit outages in a long-term planning context.
b) Minimize data requirements and computational effort, while appropriately considering the operational constraints of a system.
c) Remain independent of reserve definitions to ensure applicability across power systems.

The inclusion of such a metric would ensure that planned systems meet the dual objectives of possessing both sufficient capacity to meet system load, and sufficient ability to meet short-term net load changes. Here we propose a metric by which system flexibility can be assessed, which can be integrated with existing planning techniques, as proposed in Figure 1. This metric includes the ability to assess the flexibility of a system over an extended time period, and to consider the contribution made by all elements of the power system to meeting predicted and unpredicted net load changes[16].

Methodology for investigating flexibility: System load and VG may both set the requirement for flexibility and may contribute to the provision of flexibility concurrently. When measuring the generation capacity adequacy of a power system, the system load is the requirement which a system's generation must meet. Therefore, the first step towards developing a flexibility metric is to identify those elements which require flexibility (e.g. system load, VG and generation outages) and the resources available to provide flexibility to a system [4]. The time series of changes in net load is taken as a system's requirement for flexibility, since it represents the combined requirement for flexibility from both system load and VG. While generation outages affect the flexibility of a system, the amount of flexibility available is reduced during periods of generation outage[4].

`Conventional generation is the main existing provider of flexibility to a system but may be supplemented by curtailment of VG, interconnection to other power systems, energy storage or demand side resources (DSR), depending on the specific circumstances of the system. The flexibility of a power system is dependent on the operational policies of a system operator and, consequently, is dependent on the state of each generation resource.

Unlike generation adequacy planning, the time horizon considered plays an important part in the evaluation of flexibility. Any change in system load is rarely monotonic for long periods. Therefore, it is important to understand the system's flexibility over a range of time horizons, as data permits. The time horizon is defined as the duration of the net load change, i.e. 15 minute, 1 hour or 12 hour changes, as distinct from an observation, which is a single value in a given time series[1].

The direction of the changes in net load is an additional consideration for flexibility. The magnitude and frequency of occurrence of net load changes, and resources available to meet upward and downward changes are asymmetric. For example, resources at maximum output can only assist when net load is decreasing, while offline resources may be able to come online during periods of increasing net load.

I. Flexibility Metric: In order to remain consistent with current long-term planning metrics, it is desirable to expand or adapt existing planning concepts to consider flexibility. The most appropriate existing metric is the loss of load expectation, which results in a temporal expectation of a system's inability to meet system load. By adapting the LOLE methodology, a similar expectation can be calculated for a system's inability to provide the required flexibility. Calculation of the LOLE can be broken down into two separate processes [5]. First, a resource model is built, called the capacity outage probability table (COPT), which employs unit characteristics (e.g. unit size and forced outage probabilities) to develop a probabilistic distribution of the unavailable generation capacity. From this distribution, the loss of load expectation can be calculated by summing the probabilities that there will be insufficient capacity to meet each observation in the system load time series.

The insufficient ramping resource expectation (IRRE) is the expected number of observations when a power system cannot cope with the changes in net load, predicted or unpredicted. Calculation of the IRRE follows a similar structure to the LOLE, however, rather than forming a distribution of the unavailable generation capacity, a distribution of the available flexible resources is formed for each direction and time horizon. Secondly, as with the LOLE calculation, the probability that the system has insufficient ramp resources at each observation, over each time horizon and direction, are calculated from the available flexibility distribution (AFD), from which the overall metric is computed[17]. Calculation of the IRRE for all selected time horizons provides an understanding of the ability of a system's resources to meet the variability requirements of its net load.

II. Data Preparation: In order to calculate a system's flexibility, operational characteristics are required for each generator, which is in contrast to the LOLE which only requires knowledge of a resource's rated output and forced outage rate. Each flexible resource's energy production time series, which may be a historical or simulated time series, and the time series of the availability of each resource are required. The production time series for each resource is required since the flexibility available in either direction is limited by the maximum rated output and current production for upward flexibility, and between current production and the offline state for downward flexibility, assuming sufficiently long time horizons to reach these limits. By employing a production time series, the operator's adversity to risk from forecast errors is included in the resources' availability to ramp. Each resource's maximum and minimum rated output, start up time, ramp up and down rate, forced outage probability and production levels are required[1].

The time horizons studied may be chosen based on criteria such as the magnitude of ramping events or the frequency of occurrence of monotonic ramps in each time horizon. Chosen time horizons may also coincide with the start up times of a common generation technology (e.g. combined cycle gas turbine) in a system, or an important operational time frame, such as a forecast horizon. The net load ramping time series is then calculated for each time horizon, and separated into two time series of increasing and decreasing net load ramps. The net load ramp time series $NLR_{i,+/-}$, for time interval i, at observation t, can be calculated as follows:

$$NLR_{ti}=NL_t\text{-}NL_{t-i} \quad (1)$$
$$1 \le t \le |NL| - i \quad (2)$$
$$NLR_{ti+} = NLR_{ti} \quad \forall NLR_{ti} > 0 \quad (3)$$
$$NLR_{ti+} = NLR_{ti} \quad \forall NLR_{ti} < 0$$

where |NL| is the number of observations in the net load time series. Only net load observations in the direction of the IRRE being calculated are required in each case.

III. Resource Models: Formulation of a resource model for system flexibility begins with a model for each resource. For an LOLE calculation, and depending on the level of detail required, a generator can be modeled as being in one of N states, with the simplest model including two states: the outage and fully available states.

Since the flexibility of a system is determined by both the physical attributes of a system's resources and the operation of those resources, the resources cannot be deemed to be independent and the temporal correlation between the flexibility of resources must be preserved. Therefore, a multi-state model of a resource's flexibility is unsuitable here, since such an approach assumes independence between the availability of resources. However, the addition of each resource's time series of available flexibility to form a system flexibility time series results in a resource model which appropriately accounts for the interdependence between resources

1) Resource Flexibility: Starting with a resource's active power production time series observations during increasing, or separately decreasing, net load, the availability of that resource to provide flexibility in either direction can be calculated. Determining the flexibility of a resource is best explained by a notional 100 MW natural gas unit scheduled at 15 minute resolution, whose output over a 24 hour period is shown in Figure 2. The unit has an upward and downward maximum ramp rate of 4 MW/min. and a minimum generation level of 40 MW. Figure 2 shows the unit's production, with the shaded areas representing the upward and downward 15 minute flexibility available from the unit at each observation in time.

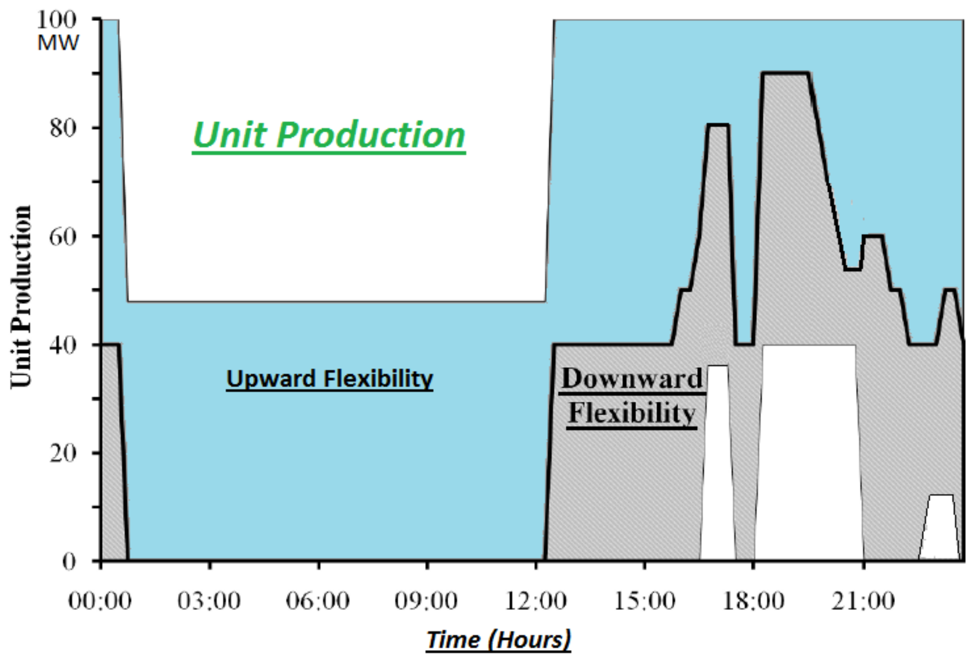


Fig. 2. Flexibility available from example unit in 15 minutes during a one day period

Calculation of the available upward (+) flexibility ($Flex_{t,u,i,+}$), for a resource u, over horizon i, at observation t in the net load ramp time series, at maximum production (ProdMAX,t,u), or while on outage, is trivial, since the resource cannot offer any upward flexibility. When a resource is offline it cannot provide any flexibility, unless the start up time, Su, for that resource is less than the considered time horizon, and it has sufficient time to reach minimum stable production. If the unit can meet this start up criterion, the upward flexibility is the upward ramp rate, RRu,+, multiplied by the remaining time once the start up time is subtracted from the time horizon. This is shown in Figure 2, where the unit has a 3 minute startup time and so can reach an output of 48 MW in 15 minutes from an offline state. Upward flexibility is bounded by the maximum production capacity of the resource. For part load production, the upward ramp rate, the maximum and minimum stable production levels, GenMAX/MIN,u, may be binding constraints on the available flexibility. Equations 4 to 6 summarize the upward flexibility available from each unit at each observation in the production time series when the unit is available. Onlinet,u is the binary online variable for each resource.

$$Flex_{t,u,i,+}=RR_{u,+} * (i-(1-Online_{ut,u}) * S_u) \quad (4)$$
$$s.t.\ \ Prod_{t,u}+Flex_{t,u,i,+} \ \leq\ Gen_{MAX,u} \quad (5)$$
$$Prod_{t,u}+Flex_{t,u,i,+} \ \in\ \mathrm{R}\backslash(0,\ Gen_{MAX,u}) \quad (6)$$

As with upward flexibility, calculation of the downward flexibility on outage is trivial, since the resource cannot decrease its output. At maximum or part load production, the available flexibility is constrained by the downward ramp rate and by the minimum stable production level. Figure 2 demonstrates that the minimum generation constraint on downward flexibility is active between 18:00 and 21:00. Upward and downward flexibility should be calculated for each unit and for all chosen time horizons. Equations 7 to 9 summarize the downward flexibility available from each unit at each observation in the time series.

$$Flex_{t,u,i,-}=RR_{u,-} * i * Online_{t,u} \quad (7)$$
$$s.t.\ 0\ \leq\ \ Prod_{t,u}\text{-}Flex_{t,u,i,-} \quad (8)$$
$$Prod_{t,u}\text{-}Flex_{t,u,i,-}\ \in\ \mathrm{R}\backslash(0, Gen_{MIN,u}) \quad (9)$$

The above logic can be extended to include resources which can consume as well as produce power, or which have ramp rates as a function of resource output. Once the flexibility available from each resource is calculated, a system wide resource model can be created.

2) System Flexibility: Addition of the individual resource time series results in a system flexibility time series ($Flex_{t,SYSTEM,i,+/-}$) which maintains the temporal dependency between generators, arising from unit commitment and economic dispatch decisions.

The available flexibility distribution ($AFD_{i,+/-}(X)$) is the empirical discrete cumulative distribution function of the flexibility available, X, which is calculated from the system flexibility time series, from Equation 10, using the KaplanMeier estimator of cumulative density functions[8]. This fulfils the same role as the capacity outage probability table, used in the calculation of LOLE. Figure 3 outlines the $AFD_{15\ min}+$(X) and $AFD_{15\ min}-$(X) for a system comprised of two units, identical in type and schedule to the example unit in Figure 2, for a one year time series. The

$AFD_{i,+/-}(X)$ indicates the probability that X MW, or less, of flexible resource will be available during the i time horizon.

IV. IRRE calculation: The probability of insufficient flexibility being available to a system operator at each point in time is the cumulative probability that the system will not be able to provide the amount of ramping required by the net load change at that point in time.

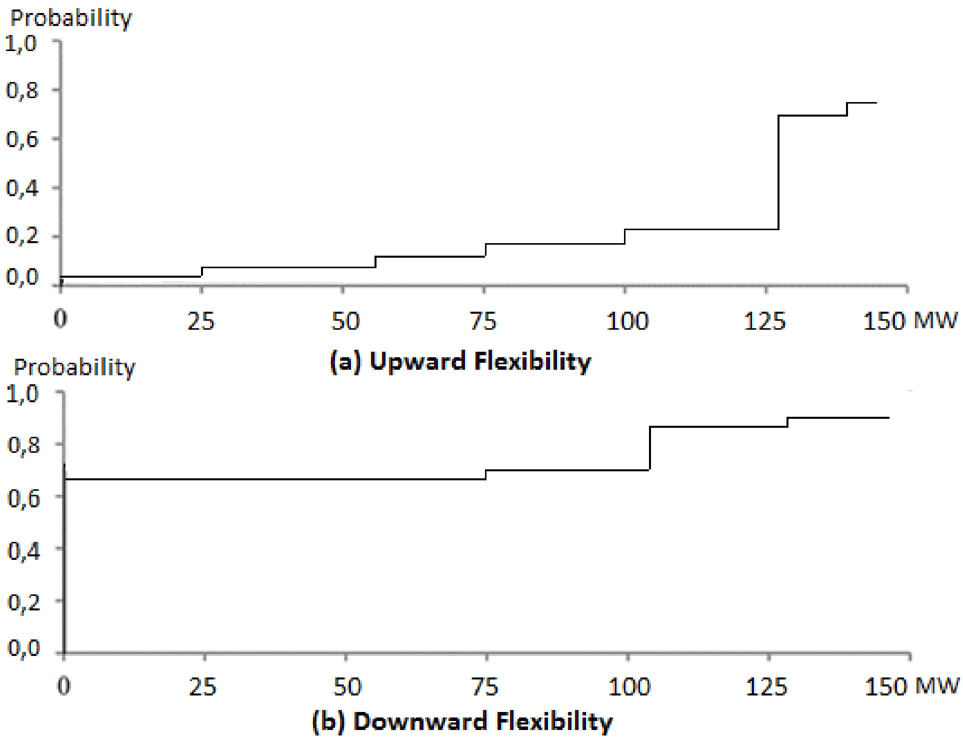


Fig. 3. AFD 15min.(X) in (a) upward and (b) downward directions

In order to exclude those cases when just enough flexibility is available in the $AFD_{i,+/-}$(X), the net load ramps must be reduced to a value just below the net load ramp value. In this case the magnitude of each net load ramp is reduced by 1 MW. Therefore, the insufficient ramping resource probability (IRRP) at each observation, t, for each time horizon, i, is:

$$IRRP_{t,i,+/-}=AFD_{i,+/-}(\ NLR_{t,i+/-}\ \text{-}1) \qquad (10)$$

where $NLR_{t,i,+/-}$ is the net load ramp at observation t in either direction.

Assuming notional 15 minute upward ramps during a 4 hour period of 45 MW/15 min., 60 MW/15 min., 115 MW/15 min. and 5 MW/15 min. the IRRE15min.,+ can be calculated for the two resource example using the upward $AFD_{15,+}$ in Figure 3(a), as:

$$IRRP_{15\ min.,+}\ = AFD_{15,+}\ (45-1)+ AFD_{15,+}\ (60-1)+AFD_{15,+}\ (115-1)+ AFD_{15,+}\ (5-1) =$$

$$= 0.0429+0.0429+0.8395+0.0294 = 0.9547 \text{ 15 minute periods/4 hr}$$

Therefore, this hypothetical system consisting of two peaking gas resources cannot meet the upward changes in the net load with an IRRE 15 min.,+, of 0.9752 observations in these four hours. This would represent a very high probability that the system will face a shortage of upward flexibility.

Results: a) Upward flexibility: System flexibility is calculated for all time horizons from 15 minutes to 24 hours in 15 minute steps, Figure 4. The IRRE is given as a percentage of the number of upward ramps for that time horizon, during the study period. In general, the system has sufficient upward flexibility for time horizons greater than 6 hours as units 3 - 6 may provide flexibility from an offline position. As expected, the 60 MW of reserve provided for in scenario (C) tends to increase the number of online resources, and therefore, the flexibility available in this scenario. This results in the lowest $IRRE_+$ across all time horizons. Intuitively, the outage of resources with no reserve provision, in scenario (B), will result in the highest IRRE+ values, given that the system will have fewer means by which it can provide flexibility when resources become unavailable.

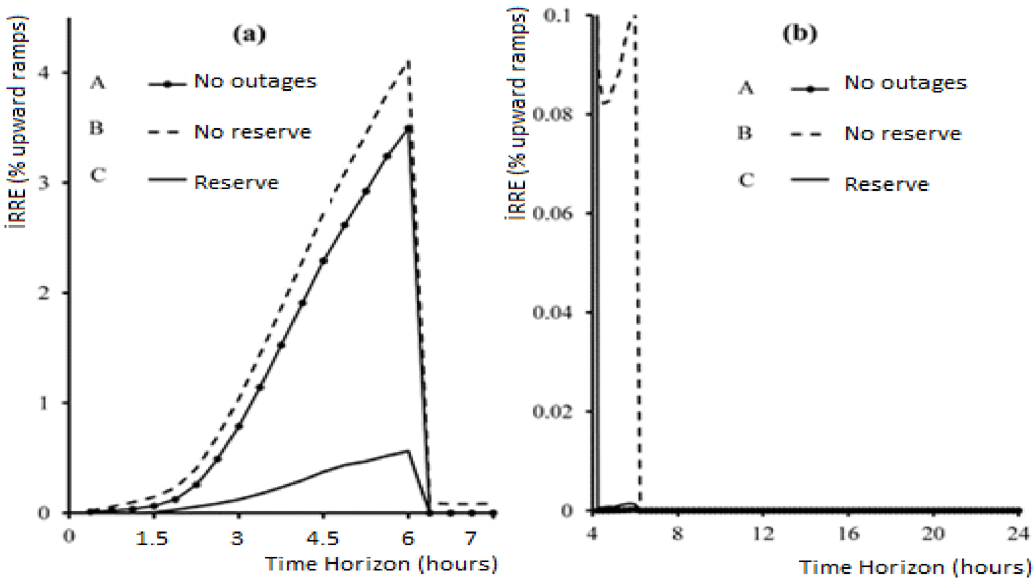


Fig. 4. Upward IRRE test system results with 50 MW of wind. The scale on the vertical axis changes between the (a) 0 and 7 and (b) 4 and 24 hour timescales

Figure 4 shows distinct peaks occurring at the 4 and 6 hour time horizons, since the system operator may only call upon one resource (unit 6) to provide flexibility from an offline state for time horizons less than 4 hours, and only two units for time horizons less than 6 hours (units 5 & 6). These peaks could pose a serious threat to the operation of the system, and planners could draw the conclusion that additional resources should be targeted at providing flexibility to reduce these peak $IRRE_+$ values. Between 6 and 24 hours, the $IRRE_+$ decreases from a peak of 0.1% for the 6 hour time horizon to 0% for all time horizons between 6.25 and 24 hours, when 60 MW of reserve is provided, scenario (C).

The contrast between scenario (A), when no outages occur, and scenario (B), when outages occur, provides insight into what might happen if imperfect forecasts of net load are used. Introducing unexpected changes in net load will increase IRRE values further, since the risk of having insufficient flexibility is increased. However, the consumption of flexibility by generation outages contributes to the high $IRRE_+$ values in scenario (B), which is alleviated by the possible commitment of units 3 or 4 in time horizons greater than 6 hours.

b) Downward flexibility: The downward flexibility is calculated for the system with both 50 MW and 100 MW of wind generation capacity and 60 MW of reserve. It is worth noting that the maximum time required for the least flexible resources (units 1 and 2) to ramp from maximum output to an offline state is 1 hour 15 minutes; therefore, all resources in the test system can provide maximum flexibility beyond this period. Consequently, the only remaining driver of IRRE− values is the downward net load ramping time series[9].

The system is sufficiently flexible to meet the ramping requirements of the system with 50 MW of wind generation (scenario (C)) over all time horizons, as shown in Figure 5. These units have relatively high minimum generation levels, resulting in the potential for inadequate availability of downward flexibility. The $IRRE_{-}$ is zero for time periods between 15 minutes and 5 hours since the magnitude of net load changes are small and there is always sufficient down flexibility to meet the largest downward changes in these horizons.

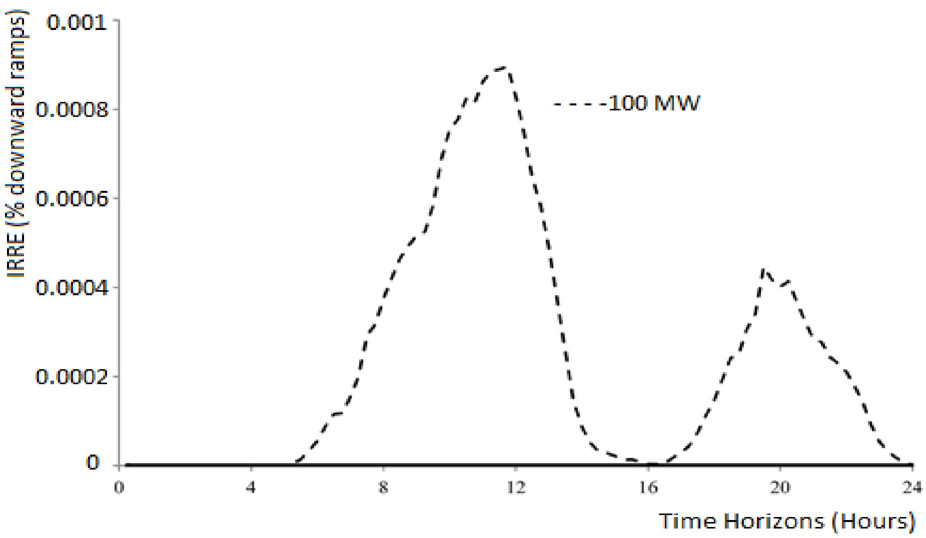


Fig. 5. Downward IRRE test system results with 50 MW and 100 MW of wind generation capacity

The 11.75 hour horizon represents the difference between the daily peak load in early morning and the midnight valley. Similarly, the 19.75 hour horizon represents the difference between the peak load on a Friday evening and the lower weekend load. The peak $IRRE_{-}$ of 0.0009% occurs at the 11.75 hour time horizon (Figure 5), indicating that the system is unlikely to face a significant threat from decreasing net load. In comparison, the IRRE+ for the system at the 4 hour time horizon reaches 0.05% of upward ramps per year for scenario (C) (Figure 5), significantly greater than the maximum $IRRE_{-}$, and represents the most challenging time interval for system flexibility[6].

Conclusion: The challenge currently being faced by many power systems is to plan for secure and reliable operation with the integration of a high penetration of VG. In response to a need to quantify a system's ability to meet changes in system load and variable generation, the IRRE metric provides a means of measuring a system's flexibility over different time horizons and directions. The IRRE potentially offers those involved in planning with a means to measure a system's flexibility, to highlight the time horizons of net load ramping in which the system is most vulnerable, and a tool to improve portfolio development.

The IRRE was demonstrated on a test system, with the addition of variable generation, to highlight the time horizons of concern to the successful operation of the system, and the impact of increasing VG on system flexibility. It is shown that the addition of VG may decrease the IRRE of a system over certain time horizons, while requiring increased flexibility in others. Peak IRRE+ values for the test system are seen to coincide with the start up times of blocks of flexible resources, in comparison to the IRRE−, which is seen to be driven by the magnitude of net load changes.

References

[1] M. O'Malley, J. Adams *et al.*, *Flexibility Requirements and Potential Metrics for Variable Generation: implications for System Planning Studies*. Princeton, NJ: NERC, 2010. [Online]. Available: http://www.nerc.com/files/IVGTF Task 1 4 Final.pdf

[2] Integration of Variable Generation Task Force, *Accomodating High Levels of Variable Generation*. Princeton, NJ: NERC, 2009. [Online]. Available: http://www.nerc.com/files/IVGTF Report 041609.pdf

[3] EirGrid, "Generation adequacy report: 2011 - 2020," *Available: www.eirgrid.com*, 2011.

[4] E. Lannoye, M. Milligan *et al.*, "Integration of variable generation: capacity value and evaluation of flexibility," in *Proc. IEEE Power and Energy Society General Meeting*, Minneapolis, USA, 2010.

[5] R. Billinton and R. Allan, *Reliability Evaluation of Power Systems*, 2nd ed. Plenum, 1996.

[6] D. Kirschen, J. Ma *et al.*, "Optimizing the flexibility of a portfolio of generating plante to deal with wind generation," in *Proc. IEEE Power and Energy Society General Meeting*, Detroit,USA, July 2011.

[7] EnerNex Corp., *Eastern Wind Integration and Transmission Study*, National Renewable Energy Laboratory, 2010.

[8] NREL, *Western Wind and Solar Integration Study*, National Renewable Energy Laboratory, 2010. [Online]. Available: http://www.nrel.gov/ wind/systemsintegration/pdfs/2010/wwsis_final report.pdf

[9] G. Calabrese, "Generating reserve capacity determined by the probability method," *Trans. American Institute of Electrical Engineers*, vol. 66 , no. 1, pp. 1439 – 1448, Jan. 1947.

[10] R. Billinton and M. Fotuhi-Firuzabad, "A basic framework for generating system operating health analysis," *IEEE Trans. Power Syst.*, vol. 9, no. 3, pp. 1610 – 1617, Aug. 1994.

[11] W. Hung, "Transmission system requirements and ancillary services provision," in *IET Seminar on Power Gen. Control*, 2007, pp. 37 –53

[12] Deutsche Energie Agentur GmbH, *Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020*. Deutsche Energie Agentur GmbH, 2005.

[13] C. Loutan, D. Hawkings *et al.*, *Integration of Renewable Resources*, California Independent System Operator, 2007.

[14] R. Doherty and M. O'Malley, "New approach to quantify reserve demand in systems with significant installed wind capacity," *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 587 – 595, May 2005

[15] RWE, *The need for Smart Megawatts*. RWE, Dec. 2009.

[16] E. Ela and B. Kirby, "ERCOT event on February 26, 2008: lessons learned," National Renewable Energy Laboratory, Tech. Rep., 2008.

[17] A. da Silva, W. Sales *et al.*, "Long-term probabilistic evaluation of operating reserve requirements with renewable sources," *IEEE Trans. Power Syst.*, vol. 25, no. 1, pp. 106 – 116, Feb. 2010.

[18] D. Bunn, "Forecasting loads and prices in competitive power markets," *Proceedings of the IEEE*, vol. 88, no. 2, pp. 163 – 169, Feb. 2000.

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Nurali Yusifbayli is Vice Rector of Azerbaijan Technical University. He graduated from Kiev Polytechnic Institute in 1986. N. Yusifbayli received his degree of Candidate of Technical Sciences in 1995, and Doctor of Technical sciences at the Azerbaijan Scientific Research and Design-Prospecting Power Engineering Institute in 2004. His research interests include: reliability and security of power systems, development of national and interstate electric power systems, SCADA, green energy and energy efficiency.

Aghaliyev Nijat (born on November 09, 1994 in Khachmaz region, Azerbaijan) studies for a PhD at Azerbaijan Technical University. . He works as electromechanical engineering supervisor at Complex Drilling Works Trust, SOCAR since June, 2018. His research is concerned with the flexibility of power systems with high penetrations of variable generation based on smart technologies. He is also interested in advanced modeling and control techniques applied to power plant.

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