APPLICATIONS OF ADVANCES IN AUTOMOTIVE ELECTRONICS TO RURAL ELECTRIFICATION: THE 42 V POWER-NET FOR RURAL POWER DISTRIBUTION

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***Abstract*--In this paper a brief revisit is made to the electricity distribution systems of the 19th century. The authors then make a leap into the future: thanks to the foresight of the Partnership for a New Generation of Vehicles (PNGV). The argument is made that the new proposed 42V dc automotive system can be applied with advantage to rural electrification.**

I. INTRODUCTION

Electrification, a key ingredient in the delivery of modern life's basics like, health, education, communication and light, remains largely elusive for most African rural communities. In fact there's no other region in the world with a lower per capita level of electrification than sub-Saharan Africa. In the East African Community states of Uganda, Kenya and Tanzania the national average per capita electrification is less than 8%. Kenya with the relatively bigger economy, and with 75% [5] of its population living in the rural areas, has a per capita rural grid electrification of less than 1%!

Historically, a combination of politics and policy, have been to blame. For example, all electric generation and distribution was legally reserved for the state power utilities. However, in recent years these governments have formulated policies with clear intent to electrify the rural areas. Legislation has done away with the traditional state utility monopolies and opened the way for private investor participation. Among the obstacles that now remain is the high cost of constructing grid infrastructure, especially in scattered and sparsely populated remote communities with low load requirements.

It has long been recognized that the traditional standards used by utilities to construct distribution networks are only optimized for urban and industrial environments. In 1935, Morris Cooke [3], the head of a newly created Rural Electricity Administration, REA, in the USA wrote in an article, "…. Since utility company ideas as to what constituted sound rural lines have been rather fancy, such costs were prohibitive for most farmers". Surprisingly, though, this caution remained largely ignored.

In its report, the World Bank [4] has recommended that, "there is need to break out from the standard mold, to review specific needs of a community, to go back to the basic principals, and to develop designs that most cost-effectively address these needs." In Nepal, for example, some savings in rural power distribution using so-called intermediate voltages, ranging from 1kv to 3kv, have been reported. Such efforts could be complemented on the demand side by use of ultra efficient consumer appliances.

The 21st century has been ushered in by a renaissance of several technologies from past centuries. Among these are, the fuel cell and distributed power generation (DG). The reluctance machine built by Davidson as a traction drive for an electric locomotive, in 1838, is currently a subject of immense interest. In 1912 General Motors rolled out a Cadillac model that had an integral starter-generator (ISG). Today, it is "state-of-the-art". In the continuing quest for answers to third world rural electrification, it would seem reasonable to take cue and probe back into these same periods for possible clues.

Turning to more recent times, particularly in the past decade, technological revolutions in energy efficiency have been unfolding. In 1993 major stakeholders in the US automotive industry set a goal to treble the fuel economy of an ordinary family sedan, without affecting its price or compromising safety and emission requirements.

On another front solid-state lighting (SSL) has been making great strides since the early 1990's. In the 18 months, leading to the beginning of 2002, alone, the market share of light emitting diodes (LEDs), in the traffic light and signal industry, in North America, increased from 8% to 20%. Energy savings of up to 80% were reported. Market penetration projections, for LEDs, for general lighting, made by Sandia National Laboratories and other key industry players are very optimistic. Improved efficacies and lower prices for white LEDs are expected over the next decade. In conformity the US Senate launched, in July 2001, 'the Next Generation Lighting Initiative', with an ambitious goal to achieve a 25% market penetration for white LEDs by the year 2012. The subsequent passing of US Senate bill S.517, on the 25th April 2002, committing over 1 billion US dollar per year, for research and development (R&D) in such areas as "next generation lighting technologies", underscores the optimism in the field.

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The following sections illustrate how these technologies are well suited for rural electrification.

II. A CASE FOR DIRECT CURRENT

In May 1893, the Board of Directors of Cataract Construction Company (in USA), which was charged with administration of the proposed Niagara Falls hydroelectric generating project, approved the adoption of alternating current (ac), in preference to direct current (dc). This decision was soon to have a profound and lasting impact on the rest of the world.

For George Westinghouse, the winning contractor, "it was the triumphant end to a brilliant struggle" [2]. But was it genuine technological triumph? There's no doubt that the discovery of ac and invention of related technologies have had a tremendously positive impact on modern industry and society. However, the adoption of ac was to the total exclusion of dc in mainstream power delivery. Could this have been an unfortunate historical mistake? For his views in support of dc, Thomas Edison, has been popularly referred to by historians as arrogant and stubborn. If today's technology had been available then, would the same decision have been made?

In fact this question is being revisited for a number of applications including shipboard power systems. High voltage direct current (HVDC) is already widely used worldwide for bulk transmission over long distances or to interconnect ac systems of different frequencies. Thus dc has always been used, with a wider range of applications emerging with the advances in power electronics.

Prior to the roll out of the Niagara power, a well-established and viable electrical infrastructure existed in the form of distributed dc generation [1, 2]. It had grown from a multitude of small and manageable units. This must have served to prepare ground for system planners before the construction of larger systems like Niagara. With the relegation of dc out of mainstream power delivery, energy storage technology was denied the massive consumer demand that could have given it the impetus to keep apace with other modern technologies. Consequently, the most popular storage, today, the lead acid battery, is hardly different from Count Alessandro Volta's invention, in the 18th century!

Could the current African rural electrification problems be partly due to application of post-Edison-like designs and distribution infrastructures, to pre-Edison-like situations?

III. A CASE FOR 42V DC POWER-NET

In September of 1993, a summit between US President Bill Clinton and the CEOs of Chrysler (now DaimlerChrysler), General Motors and Ford Motor Company, inaugurated a partnership for a new generation of vehicles (PNGV). The partnership was a collaborative research and development program between the US government and the United States Council for Automotive Research (USCAR), represented by the president and the CEOs respectively. The mission statement was short: to produce an affordable and environmentally friendly medium size family car capable of achieving a fuel economy of up to 80 miles per gallon (33.8 km/liter) and meeting safety and emission requirements. The PNGV identified the systems that required radical re-innovation to obtain appropriately efficient power trains and reduced parasitic losses. Subsequently resources from 19 federal laboratories, universities, automotive suppliers, several US federal agencies and departments and USCAR were mobilized. In the meantime similar efforts had begun elsewhere in Europe and Japan [6] and an international collaborative effort followed.

These automotive industry stakeholders considered a worst case, electric loading, scenario in the time frame period 2005 – 2015, and the most suitable electrical architecture and adopted 42 volts as the standard for the next automobile generation. Finally every component and aspect of the automobile has been re-examined from its fundamentals.

IV. AUTOMOTIVE SOLUTIONS FOR THE RURAL ELECTRIFICATION SCENARIO

The problems of third world rural electrification are characterized by remoteness and scarcity of resources. A remote rural village and an automobile share a common sense of isolation: a sense of finite resources that must be economically utilized while at the same time not compromising the quality of service delivered.

Additionally, the nature and type of rural load problems are similar to those of an automobile. These include, poor load factors, inefficient appliances as well as consumer behavior. The PNGV tackled the load factor problem by creating a hybrid electric vehicle (HEV) design. A smaller than usual internal combustion engine as the primary power plant, is sized at about average load capacity, and uses any excess energy to charge a battery. When accelerating or climbing a hill an electric motor, using the battery, assists the internal combustion engine, in a parallel drive mode.

The PNGV in 1996 selected candidate technologies for addressing the storage problem, which included the flywheel, ultra-capacitors, chemical batteries and fuel cells. The Ultra-capacitors were subsequently discontinued on grounds of cost and low specific energy. In the case of the flywheel, research has continued only for extra terrestrial applications as the PNGV expressed concerns, not due to performance, but safety, mainly due to rotor fragmentation. These concerns are, however not shared by a rural user as underground containment has been shown to satisfactorily address the issue. Unlike other types of accumulators and energy sources like chemical batteries, flywheels have virtually no theoretical limits as to how much energy they can store or how much power they can deliver or receive.

The load factor solution has been carried forward from system level down to appliances. For example, vapor compression cycles for automotive air-conditioners have been shown to operate more efficiently with variable displacement compressors running continuously at the average load capacities as opposed to the cyclic on and off routines. As a result parasitic losses are minimized. Simulations predicting efficiency improvements exceeding 50% have been reported by Delphi Harris, a team player in the PNGV. Such a technique would make substantial impact when translated into applications like rural water pumping and refrigeration among other applications. This issue affects a number of other domestic appliances. Hoppers of electric cookers, for example, have been shown [35] to create undesirably high peak coincident load currents due to several hoppers of the same appliances even when they may be actually at low heat settings. Suggestions have been made for controller designs that operate these heaters continuously for the desired average output or software that can avoid the peak coincidences.

Another technology, which doubles as a generator and arguably, as a storage, is the fuel cell. The fuel cell is a dc generator. Originally conceived to use hydrogen as the fuel, this technology has been short-listed by the PNGV to be developed to use more easily available fuels like methanol, methane and natural gas. For rural applications this development is important as biogas, which is largely comprised of methane and carbon dioxide, can be inexpensively produced, in a rural environment, by action of anaerobic bacteria on organic waste, while valuable fertilizers are the bye products. Moreover, unlike the use of natural gas, which is a fossil fuel, biogas is a renewable fuel and therefore the process of extracting energy out of it is zero emission rated. Biogas has subsequently been tried [36-39] with encouraging success. In solid oxide type of fuel cells biogas has good efficiency ratings, particularly, in combined heat and power (CHP) modes.

Household behavior in appliance use is similar to variations in driving capabilities and this affects power consumption efficiency. As an example peak coincident loading can be avoided within a household by avoiding simultaneous use of high power appliances. These concepts can now be exploited to reduce generator requirement.

Piecemeal optimization of components or subsystems alone does not necessarily yield optimum system performance. The National Renewable Energy Laboratories (NREL) has developed, on PNGV's behalf, an automotive system optimization model, ADVISOR. It was initially developed to select candidate technology clusters that would achieve a desired objective. In this case it was to predict vehicle performance, fuel economy, and average component efficiencies over urban and highway driving cycles. Using the same approach it should be possible to appraise or optimize a proposed rural electrification project design.

V. Finance and Marketing

The UN Forum Convention for Climate Change has established mechanisms like the CDM (clean development mechanism) under Article 12 of its Kyoto Protocol to reward organized development programs in the third world that are designed to save energy or protect the environment. Under CDM, technology and finance can flow from Annex I countries to qualifying non-Annex I countries and in return these Annex I participants can earn green credits to meet their greenhouse gas emission targets. Thus adoption of those automotive technologies for rural electrification is a win-win venture.

With regard to marketing and networking, of all networks, except for food, the automotive service and parts retail industry is the most widely established in rural Africa. In Kenya this very network has for some years been operating an informal link between automotive technology and rural electrification in areas like battery charging for basic home infotainment. The next generation of automotive technologies will therefore find a friendly and virtually 'familiar' environment in rural Africa.

VI. Conclusion

DC is poised to resume its rightful role in mainstream energy delivery. The most suitable arena for the debut is the 'virgin' rural Africa where no retrofitting or discarding of existing infrastructure will be required. Generators for village renewable sources, solar, wind, biogas driven fuel cell all produce direct current (dc). The majority of rural basic loads like lights, audio, IT and telecommunications are basically powered by dc. Ultra efficient pumping and refrigeration systems are achievable with dc driven variable speed drives. It makes sense to keep the whole system as dc.

If safety concerns are considered then adopting 42v would be appropriate. Moreover this would create a convenient extension of the automotive market and reduce component prices. A symbiotic relationship between the automotive industry and rural electrification would enhance market penetration and price reductions.

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